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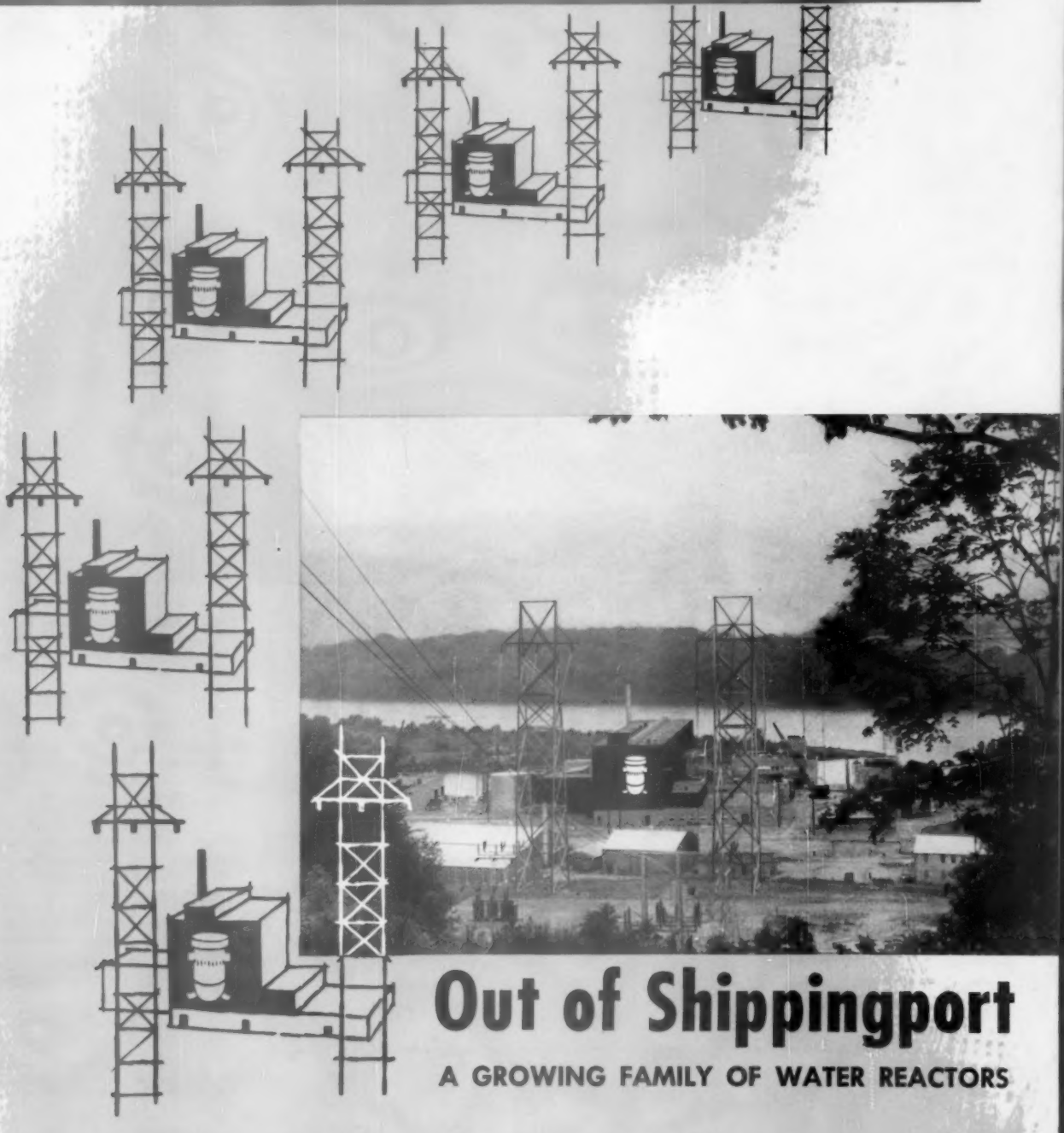
NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION



Out of Shippingport

A GROWING FAMILY OF WATER REACTORS

For NUCLEONICS Report on PWR see page 53

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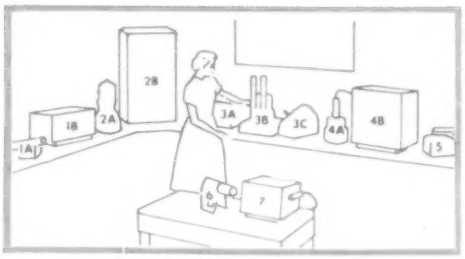

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NUCLEONICS

ATOMIC POWER
NUCLEAR ENGINEERING
APPLIED RADIATION

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About NUCLEONICS

PWR

The special report on the Shippingport reactor that is the major feature in this issue (p. 53) is designed to emphasize the significance of Shippingport rather than merely to describe it once again.

To get such a report required the help of the men who designed and built the plant. But in the last hectic months of '57 when the reactor was approaching criticality no one could be spared. However, with PWR on the line and running well it was possible to arrange for a series of interviews with the PWR project engineers (see cut) and other top Westinghouse and Duquesne officials.

NUCLEONICS GETS THE WORD ON PWR as staffers Kenton and Adamson (left) and Davis (right) interview Westinghouse's John Simpson and Joe Rengel (center)

For their invaluable help with a report of this kind we editors owe a too often unrecounted debt to the information officers of the various organizations involved. We'd like to use this space, therefore, to thank for their help with our PWR report E. J. Brunenkant of AEC's Division of Information Services, H. C. McDaniel of Westinghouse's Technical Information Division and H. Briggs of Duquesne.

Congressional Record

Editor Jerry Luntz was among those testifying before the Joint Committee on Atomic Energy during its recent "202" hearings on the state of the nuclear industry (NU, Mar. '58, 17). His testimony followed the usual format, the reading of a formal statement and the inclusion in the record of a pertinent document—in this case our recent survey on whether the U. S. reactor program should be accelerated (NU, Feb. '58, p. 17). Things got a bit rougher when he was sharply questioned by Representative Chet Holifield on a 1957 editorial that had been critical of a JCAE action. That all departed friends is attested by the following remarks which form part of the hearing record:

Rep. Holifield: We always enjoy your magazine, Sir.

Mr. Luntz: Thank you very much, Mr. Holifield.

Rep. Hosmer: It appears that it stimulates Mr. Holifield.

Rep. Holifield: It is a very stimulating magazine.

The Unrepentant Grad Student

The 8-page data sheet starting on page 78 has more of a story behind it than you might imagine.

The last such comprehensive listing of fission-product yields published was presented in 1951 ["Radiochemical Studies: The Fission Products," Division IV, vol. 9 of the National Nuclear Energy Series, edited by C. D. Coryell and N. Sugarman (McGraw-Hill Book Co.)]. A later, less complete compilation by E. D. Steinberg and L. E. Glendenin was published in the proceedings of the 1955 Geneva Conference. Since then many of the yield values have been altered as a result of radiochemical research.

Recognizing the need, we have long been after an up-to-date tabulation of fission-product yields. One of the people we went to, some years ago, was Prof. Charles Coryell of the chemistry department at MIT. He told us that he had a graduate student preparing an updated compilation as penance for having missed certain course requirements. Unfortunately, the graduate student was insufficiently repentant because the job was never completed.

Prof. Coryell did come through though; last June he put us on to the fact that Seymour Katcoff at Brookhaven had made a careful study of the literature and was in the last stages of assembling an up-to-the-minute tabulation. We contacted Katcoff; he was agreeable to our publishing it. The result of his (and our) labors appears in this issue. We know you will find it useful.

—The Editors

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Nuclear-Congress Highlights

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Geneva-Conference Planning
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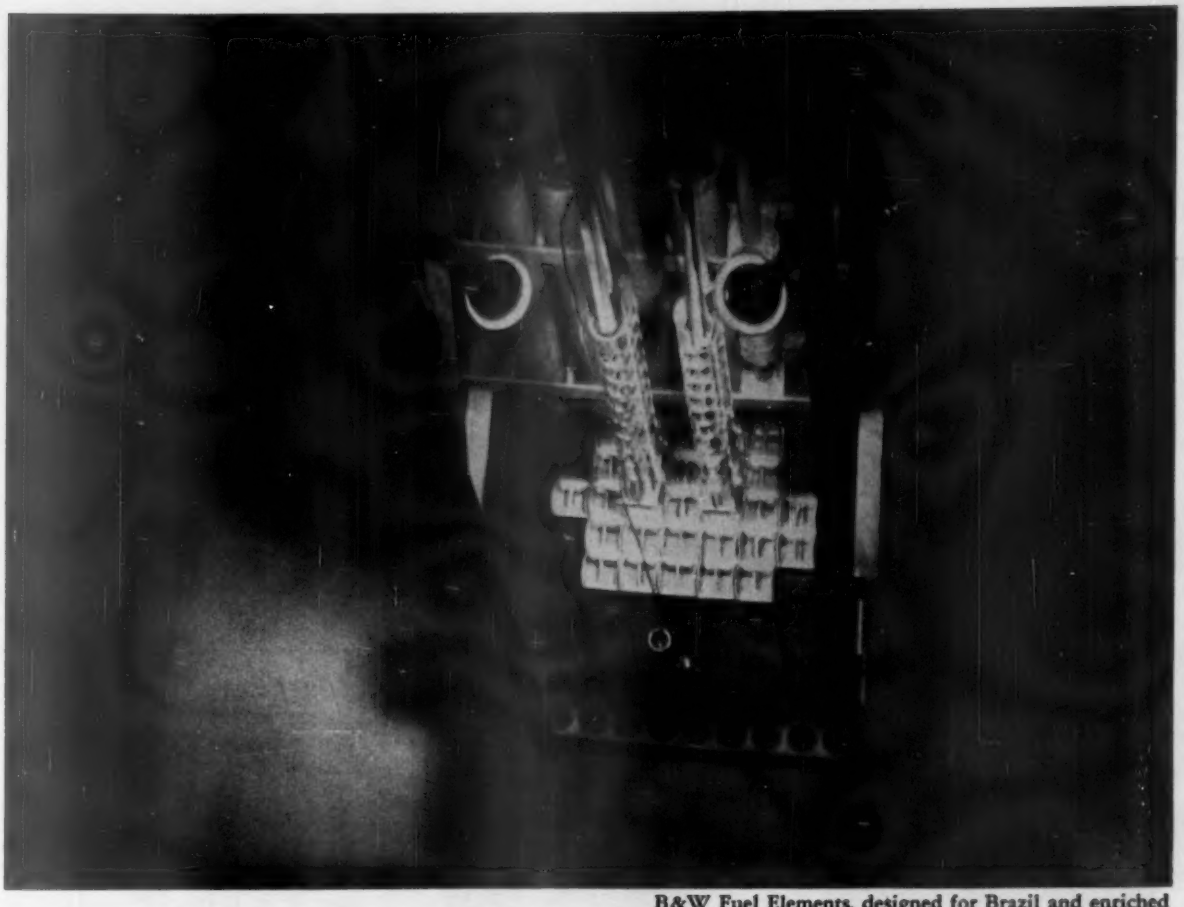
Scintillation Counting Today



B&W Fuel Elements, designed for Brazil and enriched to 20% U^{235}, shown during critical experiment.

B&W Progress Report:

Validating Core Design of Research Reactors Using 20% Enriched Uranium Elements

To confirm calculations of critical mass requirements for export research reactors using 20%-enriched uranium alloy, B&W conducted validating critical experiments with Hi-U (high-weight uranium-aluminum alloys) fuel elements. These are the elements now being supplied by B&W for South America's first swimming pool reactor at the University of Sao Paulo in Brazil. The critical experiment conducted at Pennsylvania State University under conditions duplicating those expected in Brazil is typical of the thoroughness and sound engineering traditional at B&W.

The Sao Paulo reactor, which was designed and built by B&W, will serve as a source of neutrons and gamma radiations and play an important role in Brazil's contribution to the fields of medical, biological and industrial nuclear research. Great flexibility in the arrangement of fuel elements and methods of irradiation make the B&W swimming pool reactor an adaptable, versatile research tool. This type of research reactor has the lowest cost to flux ratio of all available designs.

In addition to research reactors and fuel elements, B&W designs, manufactures and services complete nuclear power and experimental reactors and a large variety of reactor system components. Write today for further information. The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y. AE-45

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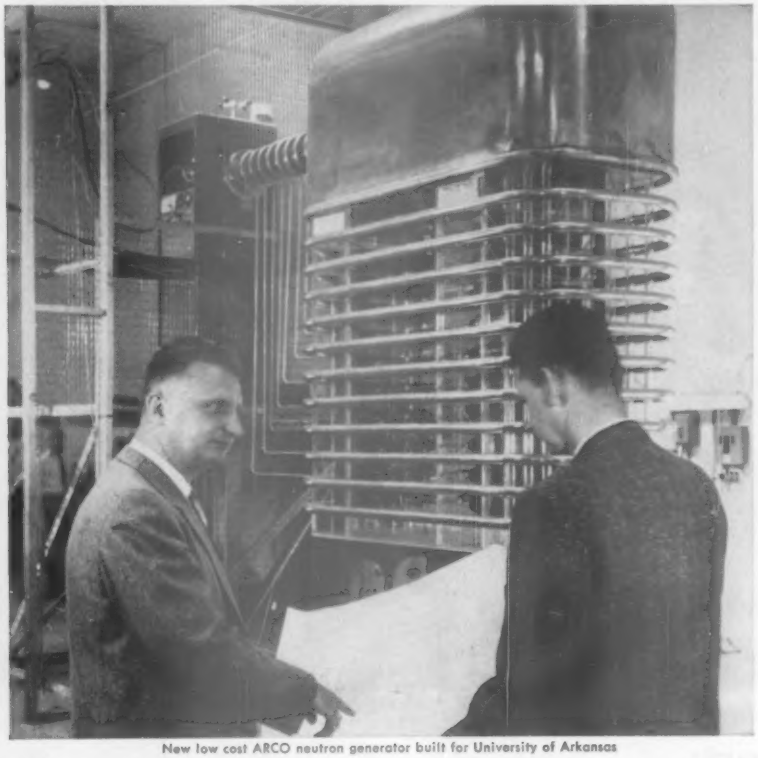


New low cost ARCO neutron generator built for University of Arkansas

10^{11} monoenergetic neutrons/second expected from new ARCO Cockcroft-Walton accelerator

The University of Arkansas expects output reaching 10^{11} monoenergetic neutrons per second from its new ARCO Model CW-D4 Cockcroft-Walton positive ion accelerator. Recently installed on the Fayetteville campus, the ARCO machine will accelerate a variety of ions for generation of monoenergetic neutrons of various energies, or for direct bombardment. The low cost accelerator was financed jointly by the University and the Atomic Energy Commission. Dr. Richard W. Fink of the University staff states that the purchase saved the University over 2 years effort had they built their own accelerator.

Research and Teaching

The versatile new machine equips the University for a broad program of physics and radiochemical research and instruction. Among the research programs planned are investigations of fast neutron cross-sections; decay schemes of short-lived nuclides; low-energy, heavy-ion nuclear reactions; and chemical states formed in nuclear reactions. By adding a subcritical assembly, the accelerator can be used as a safe device for reactor engineering instruction. Having few moving parts, the Model CW-D4 is extremely reliable. Its completely exposed power supply permits ease of service unattainable with pressurized equipment, and while accelerator dimensions are larger than those of more expensive pressurized apparatus, housing requirements are comparable.

High Neutron Yield— Precise Focus

The accelerator becomes an intense source of monoenergetic 14 Mev neutrons by utilizing the H^2 (d, n) He^4 reaction. The 400,000 electron volt Arkansas unit accelerates a 1200 microampere beam of deuterons to produce up to 10^{11} - 14 Mev neutrons per second. The machine can also accelerate protons, tritons and alphas for direct use or for production of copious yields of neutrons of lesser energy. Unusually precise focusing is attained. 1800 microamperes of 380 KV deuterons have been focused to a spot 1.2 mm in diameter.

Low Cost

Due to its simple, advanced design, the high-neutron-yield CW-D4 accelerator cost comparatively little. Funds for the ARCO accelerator were provided by the Atomic Energy Commission. The underground cell in which the accelerator is housed was built by the University.

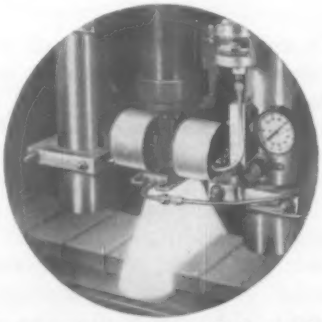
Applied Radiation Corporation can build both atmospheric and pressurized positive ion accelerators for a wide range of energy and current requirements. Exact specifications can be met. Write for details.

Linear Electron Accelerator for Rent in Illinois

The Midwest Service Irradiation Center near Chicago (Rockford, Illinois) is now available for research and production use. Operating at from 2 to 10 Mev, the Center's Mark I Series linear electron accelerator treats both thin and thick materials. Unit density materials over one inch thick can be uniformly irradiated from one side with electrons, up to 4 inches with x-rays. By cross-firing, allowable thicknesses are more than doubled.

Users gain access to one of the most powerful linear accelerators in the world without investment or operating responsibility. Yet they are able to plan their own work and retain exclusive rights to all discoveries. Users may supervise work at the Center or may merely give instructions to be carried out by Center personnel.

Write for detailed information.



Materials may be conveyed through the beam as shown or stationary experimental apparatus may be erected.

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Nitric Acid	excellent	excellent
Hydrochloric Acid	excellent	good below 10%
Phosphoric Acid	excellent to fair below 85%	poor
Chromic Acid	excellent	excellent to good
Aqua Regia	poor	excellent
Wet Chlorine Gas	poor	excellent
Chlorine Water	excellent	excellent
Sodium Hydroxide	good below 90%	good below 50%
Ferric Chloride	poor	excellent
Calcium Chloride	excellent	excellent
Cupric Chloride	poor	excellent
Sodium Chloride	excellent	excellent
Ammonium Chloride	excellent	excellent
Aluminum Chloride	excellent	excellent to fair

Chart shows corrosion resistances of zirconium and titanium to typical chemicals.

Steam jet made of zirconium, which has given trouble-free performance after a year in hydrochloric acid service. For comparison, a throat piece from a steam jet (below) is shown after only a week of similar service.

By specifying titanium or zirconium for processing equipment, you can now overcome most of the corrosive media which attack other metals.

Even with such hard-to-handle chemicals as chlorides and oxidizing acids, equipment can have extremely long service life when made from these corrosion-resistant materials. Problems of product contamination in chemical and food processing can also be virtually eliminated.

Mallory-Sharon is in position to offer you *both* titanium and zirconium mill products for equipment fabrication—plus engineering assistance and unbiased recommendations on the most suitable material.

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For information on the corrosion-resistant properties of titanium or zirconium write Mallory-Sharon Metals Corporation, Niles, Ohio.

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rigid specifications

Tension tests are required to be made at room temperatures and at 670° F. The following minimum physical properties shall be met:

At Room Temperature:

TS	YS	EL	RA	CHARPY V-NOTCH
70,000	30,000	45	50	50

At 670° F. the minimum tensile strength shall be 51,000 p.s.i. and the minimum yield strength 18,300 p.s.i.

Rejection

Each casting that develops unacceptable defects during shop working or fails to conform to all of the requirements of these specifications shall be rejected. No repair by welding or other means will be permitted.

Radiographic Inspection

(a) Paragraph S5 (a) of the Supplementary requirements of ASTM-A 362-52T.

(b) All castings shall be radiographed 100% and shall conform to ASTM-E7 1-52, Class 2 quality, except as modified by these specifications.

(c) The manufacturer shall establish a positive system of identification of the X-ray plates which shall be subject to approval by the inspector. This system shall guarantee complete coverage by radiographing and provide for positive identification between the plate and the subject.

Inspection of Penetrants

All castings shall be subjected to inspection by fluorescent penetrants or penetrating dyes both inside and out. All cracks, porosity, or flaws revealed as a result of the Dye Penetrant Test shall be due cause for rejection of the casting.

All cast pipe shall be hydrostatically tested to 5,900 p.s.i. and held at that pressure for 20 minutes with zero pipe leakage. Each length of pipe shall be hydrostatically tested at the manufacturer's plant.

The 304L stainless steel shall conform to the following ladle analysis:

Carbon	.03 max.		
Manganese	1.50% max.		
Phosphorous	.03% max.		
Sulphur	.03% max.		
Silicon	2.00% max.		
Chromium	18.00	-	21.00%
Nickel	8.00	-	11.00%

Pipe: All pipe of the following sizes shall be centrifugally cast stainless steel as per ASTM-A 362-52T, except as modified by these specifications:

16" - Sch. #160
12" - Sch. #160
10" - Sch. #160
8" - Sch. #140

All pipe shall be machine finished to 125 micro-inch interior and exterior.

for nuclear piping met by U.S. PIPE metal mold process

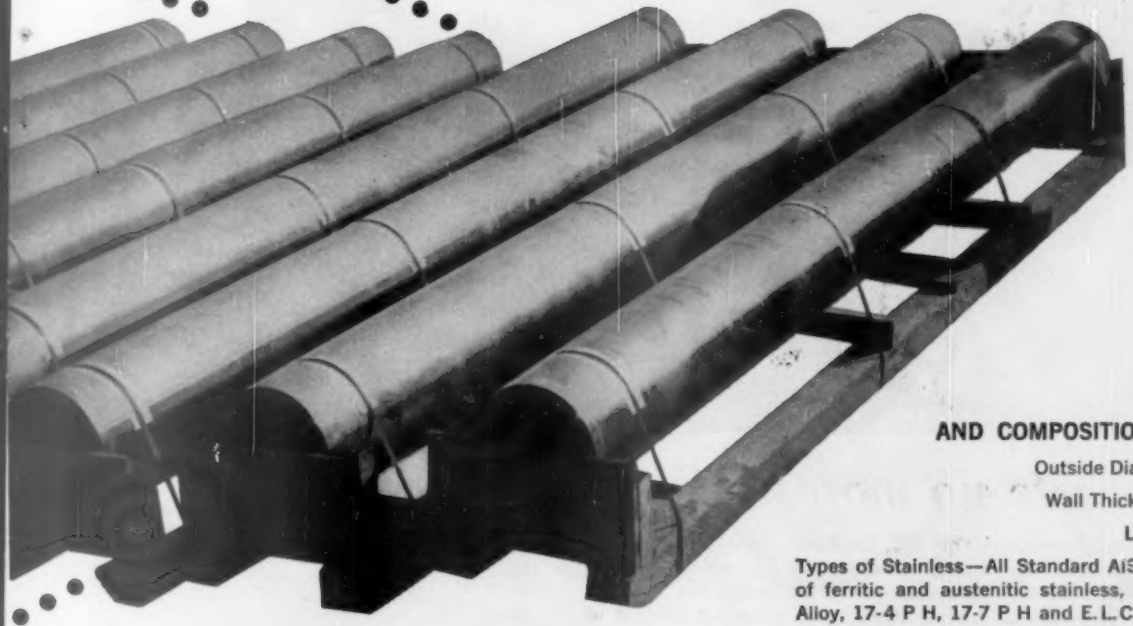
Centrifugally Cast Stainless Steel Solves Many Piping Problems

Combinations of temperatures, pressures and corrosive conditions never encountered before: these are among the piping problems that must be overcome by the men who design the nation's nuclear power installations.

Stainless steel centrifugally cast pipe provides many of the answers. Study the specifications at the left . . . specifications demanded of stainless steel pipe on a recent job for Paul Hardeman, Inc., Los Angeles, California. This pipe is being used for heavy duty, high pressure, elevated temperature service in the primary piping system of the SPERT-III Reactor at the U.S. Atomic Energy Commission's National Reactor Testing Station near Idaho Falls, Idaho. The Stearns-Roger Mfg. Company, Denver, Colorado, is the architect-engineer on this project. A complete tabulation of the actual test data obtained on this pipe and to this specification is available upon request.

U.S. Pipe is headquarters for metal mold centrifugally cast alloy and stainless steel pressure pipe over a wide range of special and standard analyses—in large and small quantities—and to individual specifications.

If piping of the type described above is the bottleneck in your nuclear power planning, write and outline the problem.



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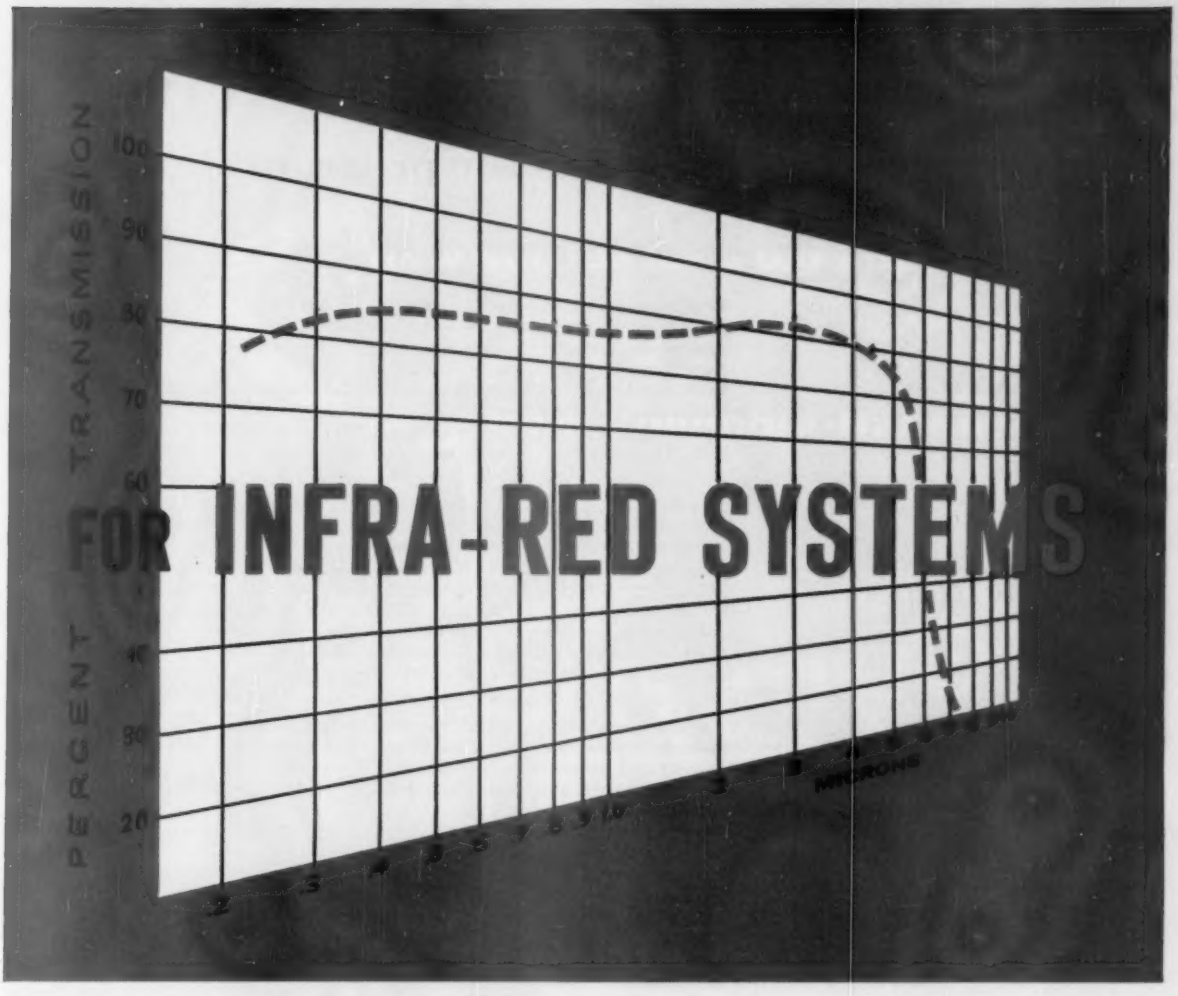

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Openings at all experience levels

ANALYTICAL	**Reactor shielding:** Advanced studies and analysis. **Reactor core:** Analysis, nuclear and reactor core. **Systems analysis:** Including engineering direction on reactor plant design – heat transfer, thermal stress, fluid flow, etc. **Heat transfer:** Direct analysis studies–reactor systems, dynamics and thermodynamics of fluid flow. Openings also in preliminary analysis, reactor operations, stress analysis, and integrated areas. Degree essential. Experience as required.
DEVELOPMENTAL	**Metallurgists:** R. & D. on nuclear fuel materials, including radiation effects, evaluation of uranium and thorium alloy, ceramics. Also for mechanical fabrication development for these materials. **Engineers** – ME & ChemE: For development of power reactor components. Devise experiments, perform tests, prepare reports. Stimulating problems in fluid dynamics, heat transfer, full scale and model studies of fluid system components, remotely operated handling equipment, etc. Other openings with nuclear experience preferred but not essential. Degree and applicable experience required.
DESIGN	**Control mechanisms:** Senior openings, original design – including control rods, safety rods, drives, allied tooling. Also mechanical design (light and heavy) and general machine design. **Electrical:** Originate and develop major control and power systems and components. **Process systems & equipment:** Prepare layouts and specs. – pumps, heat transfer equipment. **Process instrumentation:** Reactor, auxiliary, and control systems. **Facilities – mechanical systems:** Original design – heating, ventilating, special atmospheric controls for pressure regulation, cleaning, etc. Assist on mechanical design, special handling systems, etc. **Machine design:** Heavy mechanical. Original test equipment for nuclear experiments – lead-shielded casks, remote handling cranes, etc. Machine design experience essential. **Reactor core components:** Design moderator cans, fuel elements, critical assemblies, grid plates, core supporting structures.

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Atomics International has built and is operating two power reactors—the Sodium Reactor Experiment and the Organic Moderated Reactor Experiment. Central station power plants based on these reactor concepts are in the planning stages right now. In addition, AI has just begun an advanced power reactor study for Southwest Atomic Energy Associates, a group of 15 investor-owned utility companies.

AI is expanding overseas operations. With 5 foreign reactors already in operation or being built, AI recently signed agreements with ASEA of Sweden, which has offices in 50 countries, and DEMAG of West Germany, with whom AI formed the new company, INTERATOM, in Duisburg, West Germany.

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Mr. C. D. Newton, Personnel Office, Atomics International
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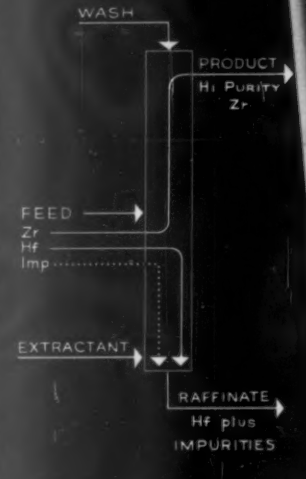

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Illustration of typical reactor core courtesy Westinghouse Electric Corporation

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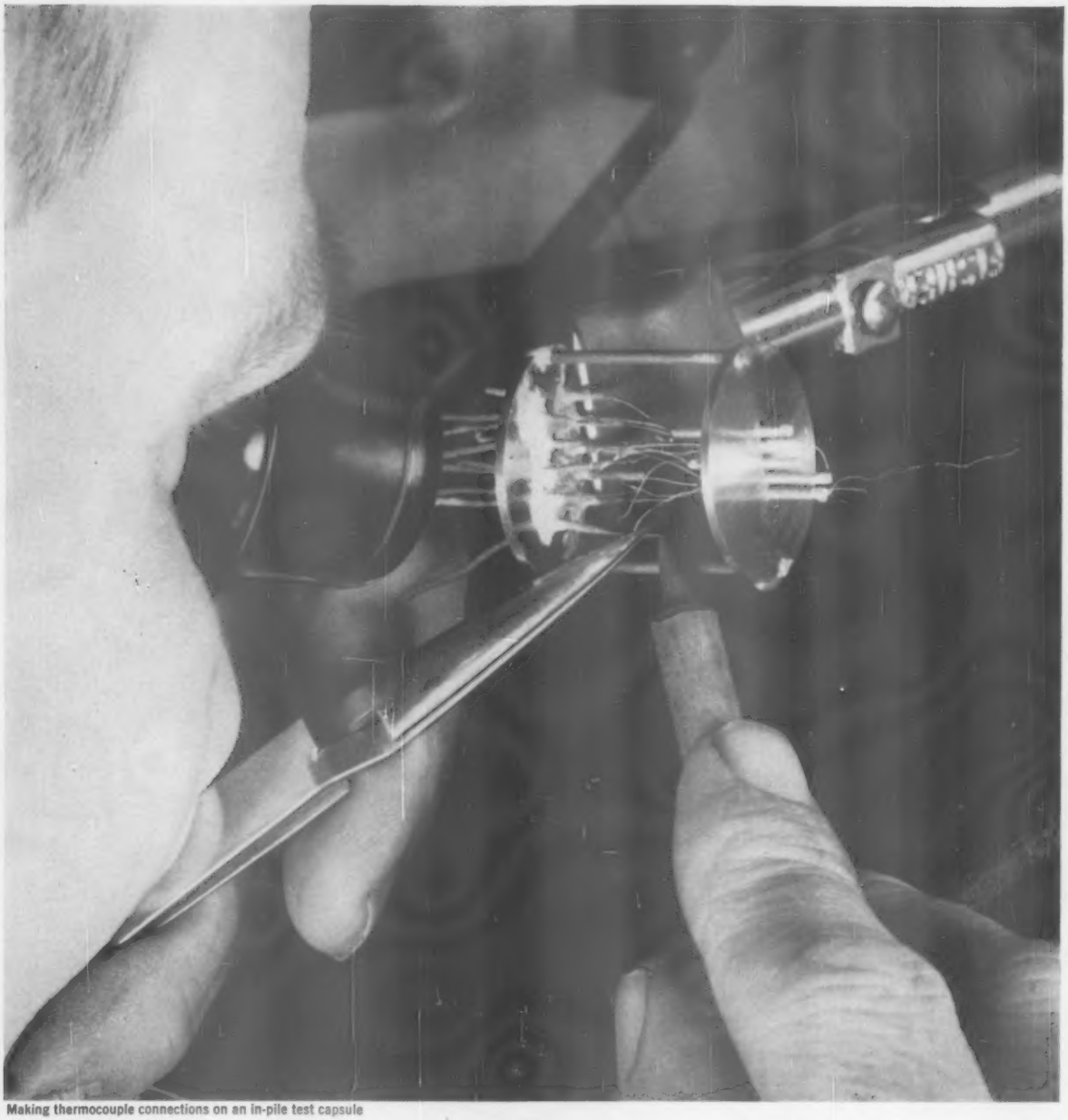

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ROUNDUP of Key Developments in Atomic Energy

JCAE, AEC Still Silent on Talks; AEC Sets 1-Year Plan

The nuclear power industry, still looking expectantly to Washington for leadership—in the form of an official pronouncement clearly stating this country's long-range objectives and the steps to achieve them—has had to content itself with another month of silence.

Four months after AEC and the Joint Congressional Committee on Atomic Energy began informal, closed-door negotiations on a program to accelerate nuclear power development, the industry has yet to get an authoritative report on progress of the talks, or where they may or may not lead.

At month's end NUCLEONICS learned that the ten-year program proposed by JCAE Chairman Durham, more recently reported as a compromise five-year program, has been rebuffed by AEC. One year ahead is as far as the Commission is willing to look.

Industry's hopes for a dramatic climax to the annual "Sec. 202" hearings—in the shape of an announcement of an accord on acceleration—were quietly quashed in mid-month when JCAE confirmed that AEC's postponed testimony on the civilian power program had been cancelled. Cause: failure to reach agreement.

Thus the 202 hearings petered out with AEC filing only a written statement summarizing the power reactor program to date and stressing the importance of tackling fuel cycle problems as against starting new reactor projects.

With 3–4 months remaining before Congress adjourns, however, the acceleration issue is far from settled. As the opposing forces girded for a renewal of the issue, this was the situation:

1. AEC will present to Congress this month a one-year program reflecting its views on how best to hasten the day of economic nuclear power, in this country and abroad, with minimal interference with the free-enterprise system. The program's major component is an expanded effort to improve technology of the nuclear fuel cycle and cut the costs of nuclear heat. It contains no provision for federal subsidies nor any significant shift in AEC's partnership policy.

2. The negotiations between AEC and JCAE have produced little more than a "target" agreement that economic nuclear power should be achieved within five years (with U. S. help) in friendly foreign areas anxious to have economic nuclear power, and within ten years in this country. There has been no meeting of minds on a long-term program to assure such an achievement.

3. AEC entered negotiations with the Euratom countries late last month (*details p. 19*). Administration sources optimistically predicted that a substantial aid program would eventually be approved by AEC.

4. AEC ran into vigorous opposition from JCAE Democrats on its plan to negotiate 15-year contracts with foreign reactor owners for purchase of plutonium produced in U. S.-sponsored reactors. The plan was attacked as a form of indirect subsidy, a type of federal aid that has been criticized repeatedly by the Democrats in their drive for outright reactor construction by the federal government (*details p. 18*).

5. The 202 hearings showed that industry opinion was weighted heavily in favor of acceleration, but the usual widely varied proposals were made on what form acceleration should take. There was near-unanimity favoring a long-term program. (*Details p. 20.*)

The Statement of Objectives

How—and for how long—to accelerate are still the burning questions midway through the Congressional session. This is true despite the fact that AEC and JCAE were able to agree last December, before the session began, on a statement of objectives for the U. S. on nuclear power.

For reasons known only to themselves, neither AEC nor JCAE has released the statement. However, Commissioners Harold Vance and John Floberg confirmed to NUCLEONICS last month that it contains these objectives:

- Achievement of nuclear power competitive with conventional power in the U. S. "as soon as practicable," or within 10 years "if a time-table is necessary." This goal is explained in terms of meeting nuclear power requirements of "our allies" and other free-world nations, because there is no pressing need here.
- Offer maximum aid to friendly countries in their "urgent" need for

AEC Stresses Fuel Cycle

AEC dropped a hint of its program's emphasis on the fuel cycle in a statement it filed on the power program with JCAE last month. The statement was in lieu of oral testimony scheduled for March 12–13 but cancelled at the last minute.

"There may be a tendency," AEC complained, "to give exclusive attention to the initiation or operation of reactor projects. Notwithstanding the very great importance of such events, one should emphasize the various supply and service functions essential for support of a reactor industry—work on fuel materials, fuel fabrication, fuel processing, utilization of fission products and radiation from by-products, waste disposal, operation of radiation test facilities, and the like.

"Some of the larger problems between us and the attainment of economic nuclear power lie in those areas."

Durham Threatens Action

"I regret to say that we are still not out of the woods in terms of revised policies and expanded programs necessary to cope with the situation," JCAE Chairman Durham told the Chicago nuclear congress.

Reviewing progress in atomic energy, Durham took swipes in passing at the nuclear plane project ("a colossal monument of maladministration by the Defense Dept.") and delays on nuclear projects due to holdback of authorized funds ("false economy and poor management by the Executive Branch"). But he dealt mostly with power development, described AEC's U. S.-financed program as "stalled," the demonstration program and private programs as "marking time."

"If, despite [AEC's] efforts, for reasons of fiscal policy or otherwise, AEC is not able to come up with an adequate program," Durham concluded, "then the Joint Committee and the Congress must try to fill the gaps."

achieving economic nuclear power "as soon as possible." This timetable is five years.

• Consider embarking on projects in the U. S. and abroad that would not otherwise be required except to assure U. S. leadership in nuclear power development.

"This objective," the joint statement reads, "emphasizes the need for a comprehensive program of assistance to our foreign friends, clearly stated and vigorously pursued."

• Provide more, but unspecified, Federal assistance "to the building of power reactors both at home and abroad," and "increase our reactor-products capability" in the face of a need for them "for a long time to come."

Even as four members of the Commission and five members of JCAE worked out this policy statement (Chairman Strauss was abroad when this happened last December), AEC was at work on a reappraisal of the reactor demonstration program. Now the results of its several-months review have been wrapped up in an acceleration program it will present to JCAE at the so-called "authorizing legislation" hearings this month, and in a supplementary budget request it will send to Congress as soon as it has been cleared by the Budget Bureau.

The AEC Program

The AEC program represents no substantial departure from the Administration's partnership policy with industry on construction of commercial-type power reactors in the U. S. Nor does it go beyond June 30, 1959 (the end of the next fiscal year) in committing Federal funds.

On the contrary, it delivers a flat "no" to the demands of some in industry and Congress that a power program of at least five years' duration be drawn up by the Federal government.

A 5- or 10-year program to succeed the original 5-year demonstration program expiring this year has been urged upon AEC by several industry leaders and at least one in Congress: Rep. Carl T. Durham (D.-N. C.), JCAE chairman.

However, at least two members of AEC—Commissioners Vance and Floberg—feel it would be unwise to make specific plans beyond one year, and Chairman Strauss is believed to be of the same mind. Commission sources said they share the view that a 5-year plan was appropriate when there was no reactor demonstration program, in 1953, but that it would be unwise to go beyond a year-to-year review now that a broad power program has been established.

"I think we are going to have a unified national program . . . which will deal primarily with fiscal '59," Floberg told NUCLEONICS. "I do not feel that now is the time to go beyond that."

Vance said bluntly that a 5-year plan was appropriate to Russia, not the U. S. "I think we ought to have a flexible plan, without reference to the length of the period," he declared. "I think our program should be modified as necessary from time to time to meet changed conditions."

AEC has come up with a fiscal '59 program calling for substantially stepped-up research and development on the nuclear fuel cycle, authority to enter into long-term Pu buyback contracts, construction of two reactors proposed by JCAE last year—plus a third, 100-Mw(e) heavy-water reactor studied by duPont (NU, Dec. '56, R5)—and continuation of the joint reactor demonstration philosophy.

Reactor development officials at AEC agreed that the heart of the program was a projected increase in research and development work on nuclear fuel. It was described as a major, three-pronged effort to shave costs all the way through the fuel cycle, with emphasis on basic research, fabrication and testing.

Basic Research. This would entail "quite a bit more effort on metallurgy, physics and chemistry" to "expand our knowledge of the fundamentals of the fuel cycle," an AEC source explained.

Fuel Fabrication. Increase the work being done on fabrication and development of fuel elements for specific reactors, chiefly those of the water type and advanced concepts.

Testing. Fabricate more partial cores and sub-assemblies, and put them into operating power reactors for life tests. "We also hope to get authority to implement our program to get more test reactors built."

The rest of AEC's "one-year program" gets into the controversial area of reactor construction. AEC is seen as ready to go ahead with two projects forced into the federal program by JCAE last year—an advanced Calder Hall reactor and a single- or dual-purpose Pu production reactor. Collaterally, AEC is carrying forward the partnership policy of the three-round Power

AEC Plan for Plutonium Buyback Barred by JCAE

AEC is suggesting that long-term government contracts to take Pu from domestic and foreign reactor-owners would also have an accelerating affect. Authorization to enter into foreign contracts was requested from JCAE in January. The scheme ran into violent objections from Committee Democrats—the most vocal being Sen. Clinton P. Anderson (D.-N. M.) and Representative Chet Holifield (D.-Cal.)—and was temporarily withdrawn.

As explained by Commissioner Vance, AEC wants authority to sign 15-year contracts for weapons-grade Pu at $30/gm and reactor-grade Pu at $12/gm. It is conceded, however, that the need for either grade is virtually impossible to gauge beyond a few years and, for this reason and others, the Democrats say they will refuse to accept the buyback plan.

Holifield pointed out that over the period of a 15-year contract "we may or may not need more material for weapons use" and "we may or may not be able to develop a fuel value." He argued that there were "other alternatives" the U. S. could commit itself to in encouraging foreign construction of U. S.-designed reactors.

"The Committee," he complained, "has been unable to get any guidance on this [future need for Pu] from either the Commission or the Defense Dept."

Despite these protests, Vance made it clear that AEC would insist on consideration of the plan by JCAE this year. It will be resubmitted, he said, during the hearings this month on AEC's plant and equipment authorization bill for fiscal '59.

Vance's view was supported by Commissioner Floberg. He explained AEC's determination to try some kind of a buyback program this way: Barring a drastic change in U. S.-Russian relations toward disarmament, "we will need Pu for weapons." Moreover, he said, "we will certainly cross the threshold [into the technology of Pu-fueled power reactors] and we will need it for fuel." With these dual needs, he argued, a purchase program of some length—if not 15 years, less—was worth attempting to draw up.

Demonstration Reactor Program.

Preliminary design studies on the gas-cooled and Pu production reactors were completed last month—the gas study by ACF Industries and Kaiser Engineers, the Pu production study by General Electric and Burns & Roe. They were required to be presented by AEC to the Joint Committee by April 1.

Funds are in the '59 budget for these and three demonstration projects presented for JCAE endorsement last month (Chugach and NDA; Florida West Coast and East Central Nuclear Groups; and Pennsylvania Power & Light and Westinghouse).

The new budget also anticipates possible AEC approval during the next year of four proposals not yet contracted for (Carolinas-Virginia Nuclear group; Elk River; Piqua; and a proposal by NDA, American Gas & Electric, and Belgian power interests).

Finally, AEC is said to be considering what may become a fourth round of the demonstration program—a proposal by Westinghouse that AEC support industry construction of two series of small prototype reactors: one series devoted to intensive core development, the other to intensive systems development. Westinghouse suggested light water approaches for the core work and the homogeneous approach for systems work. The proposal is based on the idea that developmental reactors need not be built big. The prototypes would be just large enough to permit scaling up to commercial sizes without major change.

Roddis Leaving AEC

AEC's deputy chief of reactor development, Louis H. Roddis, is leaving the Commission this summer to become president of an operating firm in the General Public Utilities System.

Strauss Renomination Seen Certain in Capital

Lewis L. Strauss, chairman of the Atomic Energy Commission, is virtually certain to be renominated by President Eisenhower before his term expires June 30, according to observers within the Commission and Congress.

However, there is considerable doubt that he will be confirmed by the Senate this session; in fact, some Joint Committee Democrats insist that he will not. One, Sen. Clinton P. Anderson (D.-N. M.), estimates it "will take weeks" for the Senate members of JCAE to review the nomination. Another, Sen. Albert Gore (D.-Tenn.), vows to revive the Dixon-Yates controversy—in detail.

If Strauss is unable to win confirmation this session, the President can be expected to give him a recess appointment and resubmit his name to the Senate early next year.

U. S. Aid to Euratom Weighed in Staff Talks

One U. S. opportunity to exert creative leadership vis-à-vis Euratom may have been booted March 13 when a Commission meeting failed to adopt staff suggestions to offer aid on fuel cost as well as research development aid to the six-nation pool. But U. S. experts off for a two-week negotiating session with a special Euratom working group were optimistic nevertheless that things were going well with plans for U. S.-Euratom cooperation.

The working group, set up Feb. 18 by the newly-appointed Euratom Commission to study and formulate a plan of action for the new pool, will meet in Luxembourg from March 20 to April 4 under Max Kohnstamm of Euratom. Sitting with them will be an American team headed by Walton Butterworth, U. S. Ambassador to the three six-nation pools (the Coal-Steel Community, Euromarket and Euratom); and by AEC deputy general manager R. W. Cook.*

According to advices to NUCLEONICS from here and abroad, Euratom is trying to figure out a new way of handling the fuel cycle for its $350-million start-up program for 1-million kw(e) capacity: four to six U. S.-designed water reactors of 100–200 Mw each. While the U. S. has never contemplated any large-scale contribution to capital cost, it has been thought that possibly a line of credit could be made available to help raise the funds—perhaps to the tune of $100-million, while European operating utilities and Euratom itself would raise the remaining ⅘ths of the money. The new European Investment Bank set up under Euromarket may offer one avenue of financing.

Another conception was that the U. S. might make the first few cores available as its contribution to a joint U. S.-Euratom development program. European firms might have cooperated with U. S. fuel-element fabricators in the development of these cores. This is the heart of the staff suggestion that was not acted on at the March 13 meeting when Commissioners Vance, Graham and Floberg failed to reach agreement on the exact form that such a program might take. It was decided instead to wait for Euratom to make the first move and come in with a statement of its needs.

Aside from the construction or fuel aid, a 10-year joint U. S.-Euratom research program to improve the performance of power reactors is also contemplated. This would involve expenditure of perhaps $100-million each, over a period of ten years, from both shores of the Atlantic.

Other objectives of the Luxembourg negotiating sessions will be: free and general exchange of unclassified information; eventual fuel reprocessing by the U. S.; lease of fuel for the life of the reactor as an alternative to outright sale. AEC says it is now ready to do this last.

In all of this, it is contemplated that this would not be a U. S. governmental aid program. Rather, the whole idea is to establish an environment in which industry on both sides of the ocean can get together and cooperate fruitfully in developing further the technology of nuclear power. This is one reason why free availability of information is among the chief aims of the talks.

The broad lines of the program have been reviewed by President Eisenhower and have his approval. The Joint Committee has also been kept informed and is likewise sympathetic.

The U. S. is understood to have made it clear that these steps, although regarded as the most important and the most urgent, are looked upon as merely the first steps of cooperation with Euratom, and that the U. S. is ready to negotiate a more comprehensive arrangement with Euratom at a subsequent date.

* Other AEC members will be Louis H. Roddis, deputy director of reactor development; Frank K. Pittman, director of industrial development; Paul C. Fine, director of operations analysis and planning; Allen J. Vander Weyden and Harold D. Bengelsdorf of international affairs division; Edwin Ferguson, deputy general counsel Nelson F. Sievering Jr. of reactor development; Amasa Bishop, atomic energy attaché in France. From the State Department will go J. Robert Schaetzel, deputy chief of the office of atomic energy affairs; Stanley Cleveland of the European desk, and a legal and a financial advisor.

EEI Task Force Recommends These Reactors . . .

Project	*Approximate Rating Mw(e)*	*Approximate Timetable*
Boiling Water with Nuclear Superheat	10–50	1958–1962
Gas-Cooled, Graphite-Moderated*	50	1959–1963
Aqueous Homogeneous Solution†	75–150	1959–1964
Fused-Salt Fueled	10	1959–1964
Steam-Cooled, D_2O-Moderated	10	1959–1965
Intermediate Energy Neutron Breeder†	10	1958–1967
Pressurized Water, Enriched Uranium Fuel	200	1959–1965
Boiling Water, Enriched Uranium Fuel	200	1960–1966
H_2O-Cooled, Graphite-Moderated, Hanford-type	250	1959–1966
D_2O-Cooled, D_2O-Moderated, Savannah River-type, Natural Uranium	250	1960–1967
Sodium-Cooled, Graphite-Moderated	200	1961–1967

* Under study by contract with AEC. † Under study by Southwest Atomic Energy Associates.

. . . as JCAE Gets Flock of Industry 10-Year Plans

The widespread interest in a long-term program for achieving economic nuclear power in the U. S. produced a rash of ten-year plans during the "202" hearings of the Joint Committee on Atomic Energy. Proposals were made by the Edison Electric Institute, Nuclear Development Corp. of America, Vitro, Texas Atomic Energy Research Foundation and Atomics International.

An 11-man EEI task force reported, after more than a year's effort, the results of "an objective review of the present status and the future prospects for the production of electric power from nuclear fuels." Its conclusion:

"There is a good probability of reducing the cost of nuclear power sufficiently in the next ten years to make it competitive with power from fossil fuels in some parts of the U. S."

To make this probability a likelihood, the task force recommended: **1.** a thorough investigation of 11 reactor concepts not yet projected for construction (*see table*) but construction only for those which study shows have economic promise; **2.** exertion of "every effort" by the government to stabilize prices for nuclear fuel and services; **3.** more research-development work on reactor fundamentals, control and fuel cycle; and **4.** high-priority effort to perfect plutonium and U-233 recycle.

The task force, headed by James F. Fairman, Consolidated Edison of New York, includes: James B. Black, Pacific Gas & Electric; Walker L. Cisler, Detroit Edison; Herbert J. Scholz (ret.), Southern Services; Philip Sporn, American Gas & Electric; William Webster, New England Electric System; Robert F. Bacher, Cal Tech; Marion W. Boyer, Jersey Standard; Augustus B. Kinzel, Union Carbide; Henry D. Smyth, Princeton Univ.; and Harry A. Winne (ret.), General Electric. Retained as consultant was Walter H. Zinn, General Nuclear Engineering Corp.

These programs were suggested by other industry officials:

John Menke, NDA. A 10-year program "directed at hard accomplishment of just one more reactor type"—heavy water plants using natural U or U enriched by less than 1%. AEC would supply design and development funds, provide low-cost rental of fuel and heavy water, and subsidize 85% of incremental cost over conventional plants for "at least one experimental and one full-scale plant in the U. S. and two full-scale plants abroad." Menke also suggested a more ambitious 10-year subsidy program costing $200-million a year, concentrating on three or four concepts and providing for construction of up to two-thirds of the plants abroad.

Norman A. Spector, Vitro. A program geared to production of competitive power by 1968; construction of 2-million kw of nuclear capacity over that period, including natural U, thorium-uranium and gas-cooled reactors; and separate programs on fuel fabrication and reprocessing.

J. B. Thomas, Texas Atomic Energy Research Foundation. A fuel subsidy program "of at least ten years," with AEC making both fuel and reprocessing available at no or reduced cost. Also, permanent changes in the law to create a better environment for private investors.

Chauncey Starr, Atomics International. Preferably a 10-year, $200-million per year construction program keyed to Federal subsidies, but, at least, a fuel and construction subsidy program for U. S.-designed reactors built overseas (NU, Mar. '58, p. 18).

European Insurors In Pool Agreement

"Widespread agreement" has been reached among European insurance men on a broad approach to insurance of nuclear power plant and processing risks. The accord was reached in a three-day meeting in London last month held by the British Insurance (Atomic Energy) Committee and attended by 35 delegates from 14 other European countries.

The British committee—corresponding to the NELIA and NEPIA insurance pools in the U. S. (NU, June '56, 21A)—represents Lloyd's and other U. K. insurance companies that have pooled their underwriting capacity to meet demand for nuclear risk coverage.

Spokesmen for the group declined to say what atomic insurance was likely to cost, but suggested it would be "insignificant" in terms of mills/kw generated. Nor would they reveal what capacity the British pool had marshaled, nor which companies have entered. The pool has already received a number of overseas inquiries.

Owner Responsible

All countries attending the conference endorsed the principle that the reactor owner/operator should accept all responsibility for radiation liabilities for contractors and suppliers as well as for himself. All claims from a third party would be made solely against the reactor owner/operator. The public would not, in any case, be responsible for insurance to its own life, limb, or property. The owner would—under a government proposal—be under an absolute liability at law, and required to insure to $14-million minimum or show equivalent liquid assets (NU, March '58, 26).

Risks would be pooled both as to third-party liability and damage to policyholder's property including radiation damage. No insurance-pool coverage would be available separately for material damage or for nuclear risk alone—the policy must be comprehensive.

Countries attending the meeting were Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Sweden, Switzerland, and Turkey.

Another meeting April 25 will consider evaluation of hazards, bases of premium rating, and policy cover to be offered.

AEC Tackling Technical, Legal Problems of 'Plowshare'; Eight Proposals Submitted by Power, Mining, Oil Firms

AEC has turned its attention to the admittedly difficult problems—both administrative and technical—of sharing the economic promise of underground atom blasts with private industry.

The detonation of a 1.7-kiloton-equivalent atomic bomb at AEC's Nevada test site on Sept. 19, 1957, has brought a mixed reaction from private industry. Some in the nucleonics industry see a "Buck Rogers" cast to the recent statements of AEC officials that the successful September shot (Rainier) may lead to wide industrial application of nuclear bombs.

Nevertheless, AEC has received eight concrete proposals for industrial application from the power, mining and oil industries. And, an official of Project Plowshare told NUCLEONICS, this number "is rising fast."

Rainier was tested primarily for military reasons—to develop a weapons-testing technique which would eliminate fall-out, be independent of weather, preclude interference with aircraft, and produce no offsite effects such as noise and shock.

In these terms it was an unconditional success. More significantly, perhaps, it gave real impetus to the Plowshare project of the University of California Radiation Laboratory at Livermore—a project devoted to the study of nonmilitary applications of nuclear detonations.

The pre-Rainier attitude of skepticism within industry remains to a large extent. However, a Plowshare scientist observes, the proposals filed since Rainier show that some industrial people "have been taking the project seriously."

Generally, the proposals from industry to date have fallen into two categories—those proposing joint industry-government participation in future experimentation and those requesting AEC approval of and cooperation with unilateral projects.

"The big problem," Plowshare officials explain, "is the same as in the reactor business—the administrative problem of working out the machinery so we can work with industry."

Among other things, this involves patent claims, federal charges for bomb use, and many legal problems.

Technical Problems

Beyond the administrative problems, UCRL and the several other government contractors active in the project are looking toward a series of tests that will provide some answers to questions raised by Rainier: Are atom-bomb explosions feasible for producing steam for electrical generating stations? If so, under what conditions? Can bombs be used to restore pressure to oil fields? What are the chemical reactions that might be produced in oil, coal and other minerals? How can bombs improve mining techniques?

"We are working very hard on developing a pattern of further testing to get the answers we need to prove or disprove these feasibilities," it was explained. "They will be scientific experiments to get the answers to the various questions that have been raised by Rainier.

"We are working on designs for experimental shots that will give us information not only on power application but on mining and other uses as well."

UCRL has received two proposals for power production. These propose that nuclear devices be used as power sources to produce high temperatures. The Rainier shot produced temperatures in the range 1,200–1,500° C but the presence of large amounts of water (15–20% by weight) quickly dropped the temperature to about 100° C.

The Plowshare scientists expect substantially higher temperatures in dry surroundings. Moreover, they point out that bombs 100 times the size of Rainier (which was a mere 1.7 kilotons) can be used and that power installations can be designed to take repeated shots.

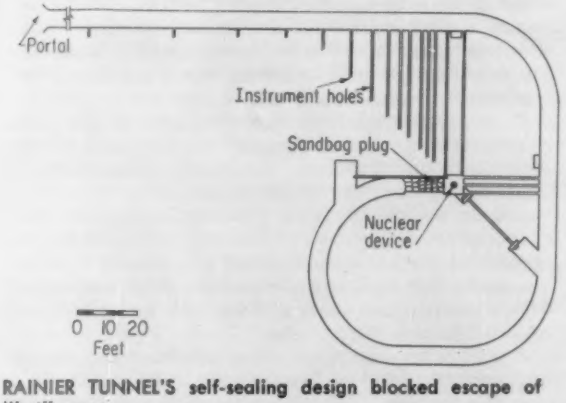
"This means a certain amount of cleverness," it was observed, "but the ingenuities are working. It's a very tough job but it doesn't look too visionary to us.

"The fact that industry is looking at it seriously and hard ought to suggest that it looks reasonable to them."

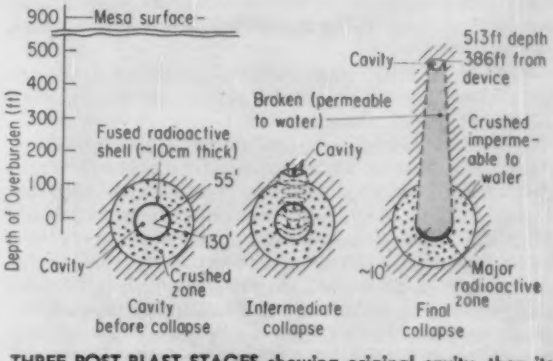
This same type of explanation was given on the question of cost. Some, if not all, of the power people interested in Plowshare are familiar with bomb costs and have been able to estimate roughly the cost of steam produced by bombs.

"Costs are not a major item," a UCRL official stated. The problem, he indicated, is primarily one of working out a meaningful federal charge. One possibility under consideration, he said, was a charge in terms of energy units produced.

It is quite another story on costs of extracting radioisotopes produced by an underground explosion. On this point, it was stated simply, "we don't know" whether it will be economic to produce radioisotopes.



RAINIER TUNNEL'S self-sealing design blocked escape of "hot" gases



THREE POST-BLAST STAGES showing original cavity, then its intermediate and final collapse

ROUNDUP

Better Industry Mood Seen at Chicago Talks

Not surprisingly, the atomic industry meeting held in Chicago last month saw a rebound by the industry from the pessimism and distress of the New York meeting six months earlier. The mood at Chicago, it was generally agreed, was one of determination—of gritted teeth and rolled-up sleeves—in facing the industry's two great and tightly-related questions: where are the profits? and, when will there be economic nuclear power?

The 1958 Nuclear Congress, held at two locations in Chicago six miles apart, this year combined two major meetings: a management conference sponsored jointly by the Atomic Industrial Forum and the National Industrial Conference Board, and the nuclear engineering and science meetings sponsored by 29 professional societies. Also competing for the time of harrassed attenders were the Atomfair and the sixth Hot Lab and Equipment Conference.

New Reactor Ideas

Dust fueled. A new fuel form—fissionable dust carried in an inert gas—was proposed by Armour Research Foundation. This concept has all the advantages of any fluid-fueled system with greatly reduced corrosion and high temperature capability; in an all-ceramic system 2,000° F and higher are held feasible. Breeding is seen as assured due to virtual elimination of neutron poisons. The core is a block of ceramic moderator—graphite or beryllium oxide—with vertical fuel channels; fuel dust of uranium carbide would be used with graphite, uranium oxide with BeO. Helium as carrier virtually eliminates the corrosion problem. Burnup is unlimited; control is without rods by varying fuel concentration. Two variants were proposed: an externally-cooled version, having a very simple core, high heat-removal capability and high power density; and an internally-cooled case requiring a more complex core in which the fuel-dust fluid loop and a helium coolant loop are separate. This however results in a nonradioactive primary loop, easing maintenance.

Evaporatively cooled. Use of evaporative cooling in a reactor system, using the coolant vapor directly as the turbine fluid, was advanced by two scientists from Lockheed Aircraft and Stanford Univ. This, they hold, would have many of the advantages of a boiling system such as eliminating heat exchangers, without the limitations and stability problems resulting from boiling in the core. They find diphenyl for thermal reactors and mercury for fast systems attractive coolants for use in this manner.

Reactor Projects

Nuclear superheat will be used for the first time, in the 66-Mw boiling reactor Allis-Chalmers is designing and building for Northern States Power Co. (NU, March '57, R9). Although the contract had provided for an oil- or gas-fired superheater, A-C engineers have developed a feasible nuclear superheater using a core divided into two close-coupled regions. An annular boiling region, with Al-jacketed 1.6%-enriched UO_2 pellets as fuel, produces saturated steam (489° F, 600 psig) that flows to the dome of the reactor vessel. It is then conducted down the central core region, through assemblies each of three concentric tubes containing a stainless-clad 20%-enriched UO_2 stainless cermet. This delivers 825° F, 540-psig steam to the turbine. Core size is 6 ft high × 6 ft dia., of which the center 30 in. dia. is the superheater. Although nuclear superheater fuel costs "appear to be a little higher than conventional fuels," A-C points out that all nuclear heat is absorbed by the steam, whereas a conventional superheater wastes considerable heat; also, that less than 20% of total heat is superheat. A-C sees development of low-enrichment fuel for superheating as reducing nuclear fuel costs to competitive values. A-C is also studying the feasibility of eliminating containment on later versions.

Nuclear plane progress was reported in five papers from General Electric's Evendale, Ohio, ANP plant. Details unfortunately were

Eisenhower Kills 'Early Flight' Nuclear-Propelled Plane;

The early-flying version of the nuclear-propelled airplane has been grounded by the personal intervention of President Eisenhower himself. Despite the vigorous urging of Joint Committee on Atomic Energy Democrats for a crash program to get a reactor-powered plane in the air as soon as possible—and before the Russians do—the day was carried by those who contend that to put a reactor into a modified KC-135 or other existing airframe would produce a "flying reactor" of no use as a weapons system.

The decision to concentrate exclusively on a nuclear plane with a specially-designed airframe involves a delay of at least a year, probably more.

The Chief Executive—whose decision drew immediate sharp denunciation from Chairman Carl Durham and Rep. Melvin Price of the Joint Committee—based his action on the need of not diverting men and materials from the effort to achieve an effective military plane. His decision was contained in a letter to Price, replying to an Oct. 24 letter from Price in which the Illinois Congressman appealed to the President to support the crash program for an early-flying plane. Price, who toured Russia last fall, is convinced the Soviet Union will have a plane flying in 18 months. He stressed the cold-war prestige value of having the first successful nuclear aircraft, in addition to its military value.

"I find no fault with either of these objectives," the President wrote in his reply, "but unfortunately, in present circumstances, they meet head on. If striving to be first were our shortest road to an operational military aircraft, we long ago would have pursued that course. But, at the present state of the art, such an effort would divert extremely scarce talent from attacking fundamental problems that must be solved before a militarily important aircraft can be produced. . . .

" . . . Our need for the development of the high-priority military aircraft overrides the first nuclear-flight objective," the President concluded. [Therefore] "I have decided that we should continue to go forward as rapidly as we effectively can with our development program, which at this stage places major emphasis on materials and reactor research, rather than to rush development of a first nuclear flight aircraft which would have little or no practical utility and would delay achievement of an effective military aircraft."

" . . . A hopeless, hapless and helpless policy of drift and indecision" is how Congressmen Price and Durham saw this decision. "This is where we have been for the

heavily shrouded by secrecy limitations, but advances in shielding, controls and activation control were reported. A sixth paper forecast for the meeting but not given described a 1/10 scale model of a shielded cab vehicle for servicing a nuclear plane, designed by Wetlaufer Engineering Inc. of Detroit—a 65,000-lb cab of 1-ft thick lead, with 28-in.-thick lead-glass windows ($20,000/pane) giving the operator panoramic vision. The cab will be part of a 150,000-lb "dreadnaught" vehicle powered by a 1,000-hp GE turboshaft T-58 helicopter engine. Wetlaufer expects an order for a $1-million vehicle.

Plutonium recycle. General Electric presented seven papers giving technical details on the $15-million Plutonium Recycle Reactor it will start building at Hanford this spring for AEC (NU, Jan. '58, 62). This will be the first U.S. reactor to use pressure tubes in a high-temperature system: 85 "process tubes" running vertically through the heavy-water moderator tank will act as so many individual fuel-testing facilities.

Testing reactors. The Westinghouse Testing Reactor will be completed near Pittsburgh in spring of 1959, and the General Electric Testing Reactor at Vallecitos in the fall this year.

EBR-2 fuel. Sylvania-Corning has developed a method for producing a perforated wafer fuel element by powder metallurgy from uranium alloys, for possible use in Experimental Breeder Reactor-2. Such "radiator-type" wafers, stacked to form a fuel assembly with integral coolant channels, would provide higher ratio of heat-transfer surface to fuel-element volume than pins or rods, are not subject to bowing as are pins, and permit unimpeded coolant flow.

Other progress notes. NDA reports unexpectedly good resistance of aluminum to corrosion by hot sodium: no corrosion on 0.06-in. Al after 16 hrs exposure to a sodium jet at 950° F. NDA is seeking a barrier material separating water and sodium systems for its Chugach reactor . . . GE's Vallecitos reactor is now having a pump installed, to permit dual-cycle and forced-circulation operation . . . Commonwealth Edison's 180-Mw(e) Dresden plant is 6–12 months ahead of schedule—an almost unheard-of situation to date in the nuclear field. Although the contract completion date is December 1960, GE and Bechtel hope to finish construction and begin testing in fall 1959, be in full operation in summer 1960. . . . The Sodium Reactor Experiment will soon go to full power. Only significant difficulties to date have been the main sodium-to-sodium heat exchanger performing below specifications, and excessive natural convection of the sodium coolant after shutdown.

Economics

• A seldom-heard point in favor of nuclear power, cost-wise, was made by Con Edison's James Fairman: "Since 1937 we've spent $45-million for cinder-catchers and other gadgets required for air pollution control; we've authorized another $18-million. At Astoria, our newest conventional plant, we're paying $5-million for cinder-catchers—that's $13/kw, 7% of costs—and we still have sulfur in the stack gas which no one has found a way to get rid of, at any price. If this keeps up maybe even the present atom-crackers may become economic." Added Commonwealth Edison's Joslin: "That's another reason we became interested in nuclear power."

• An ultimate installed cost of $180/kw for boiling-reactor power systems was predicted by Argonne.

• The family of small nuclear plants being developed by the Army shows construction costs ranging from $750/kw for a 20-Mw(e) plant to $1,500/kw at 2-Mw, and $6,200/kw for 200 kw(e), said the head of AEC's Army Reactors Branch.

• A Babcock & Wilcox analysis of enrichment costs in terms of dollar requirements abroad shows that a decision to build a new coal-fired boiler to be fed with U. S. coal will require $5.6-million for a 150-Mw plant; but purchase of enriched uranium for an equivalent plant requires only $2.8-million. Furthermore, if a nation can supply its own natural uranium feed, the dollar requirements can be further reduced to $1.45-million.

Democrats Flay 'Drift,' 'Inaction'

last ten years, and this is where we stand today.

"We had been led to believe," Price and Durham declared, "that the longstanding inaction and indecision which have characterized the conduct of the ANP program since its inception would be replaced by a vigorous and well-coordinated program aimed at an early flight capability. . . . At this point the Killian Committee [an advisory group headed by White House Science Adviser James R. Killian] stepped into the picture to 'expedite' matters. . . . We now find that the net result of all this 'expediting' has been to slow down rather than accelerate the program and that we are actually worse off today in terms of our objectives than we were a year ago, before Sputnik. This situation is patently ridiculous . . . "

On March 6 Deputy Defense Secretary Donald Quarles testified on the President's decision before a closed meeting of JCAE's research and development subcommittee, which Price heads. Quarles is reported to have told the subcommittee that it is "the best advice of scientists and engineers specializing in this field . . . [that] any early flight aircraft that could now be designed and produced would have such marginal operational characteristics as to be without value to the program even for the purpose of providing operational experience."

Price assailed the Administration position that pushing the early plane would waste scientific manpower as a "smoke screen for inaction" and "without basis in fact."

"I have been informed categorically by the people actually working on the project," Price declared, "that far from wasting manpower, the development of an early flying nuclear plane would in fact be the best possible utilization of existing scientific and engineering talent and would serve as a strong incentive for them to get on with the job. It was clearly brought out during testimony . . . that an adequate supply of such talent exists not only for present needs but for an accelerated program as well."

As for the contention that an early plane would have no utility and would delay the high-performance plane, "I believe the exact opposite to be true," Price asserted. "The history of research and development is replete with examples, such as the hydrogen bomb, which demonstrate beyond argument that successive stages of development are necessary before the finished product can be achieved and that actual operating experience is essential to test out experimental devices. Such operating experience serves as an impetus, not a deterrent, to the achievement of our ultimate objectives."

AEC Plans Acceleration of Industrial Radiation; New Oak Ridge Plant to Reduce Isotope Prices

Long unhappy about industry's failure to do more than it has to exploit radioisotopes and high-level sources of nuclear radiation, Willard F. Libby, AEC's scientific member, has swung the Commission behind a $5-million program to accelerate radiation application.

AEC's aims are three: 1. define an enlarged market for radiation sources; 2. encourage industry to exploit this market; and 3. help industry train the necessary manpower.

Libby, who had failed in recent years to persuade his fellow Commissioners to vote approval of a Federal program, succeeded last fall in getting $5-million into the AEC budget for fiscal '59, beginning July 1. He and others interested in applied radiation have long been puzzled by industry's willingness to make heavy investments in nuclear power (where return on investment is long-range) contrasted with its relatively light interest in radiation, which holds promise of more immediate returns.

"While it is true that the contribution which nuclear radiation and radioisotopes are making to human well-being has already been demonstrated," Libby declared recently, "when we compare what has been done with what remains to be accomplished, we are far from satisfied with the rate of progress in this field and are embarking on a vigorous program to explore and exploit the full potential of radiation."

For example, AEC estimates that only about 0.6% of U. S. manufacturing and mining concerns hold radioisotope authorizations, while at least 8–10% can use isotopes profitably. Moreover, high-level radiation has scarcely been explored by industry.

The Program

AEC's program to spur industrial investment in both radioisotopes and nuclear radiation were outlined last month by Frank K. Pittman, director of the new Office of Industrial Development; Paul C. Aebersold, chief of the Isotopes and Radiation branch under Pittman, and Gene Fowler, Aebersold's deputy. They said the $5-million sought for fiscal '59 covers acceleration of both isotopes and high-level radiation.

While they await Congressional action on the '59 budget, however, they have committed limited existing funds to a survey of high-level radiation use. An invitation to 18 firms to bid on a contract to conduct the survey was issued early in March. Within a week, more than 50 firms had notified the Commission that they were interested in bidding.

The successful bidder will conduct a two-stage study expected to take some six months: 1. pin-point the present and possible uses of high-level sources (100,000 to 1,000,000 curies); and 2. when this stage has indicated the area of interest, survey management for suggestions on how to increase work on high-level radiation.

"This is not intended as a literature survey in its classical sense at all," Fowler told a Nuclear Congress audience in Chicago. "We don't want a bibliography.

"What we do want is a deliberate and objective sifting of the vast storehouse of technical data which is now available and have a hard look at these to identify the technical opportunities, both immediate and long range, for specific industrial applications.

"The second phase of the contract work is intended to identify industry's need for irradiation space in facilities employing quintalcurie and megacurie radiation sources."

Is development work far enough along to support a facility capable of processing hundreds of pounds or tons of product in a megacurie radiation environment? What is industry's interest in a joint government-industry program to construct such an irradiator? These are two of the questions the AEC would like the survey to answer.

By late this year, it is hoped, AEC should be ready to outline a "definitive" program, including a decision on whether to build a high-level irradiator at Brookhaven National Laboratory.

Also, the Commission is considering the feasibility of offering high-level source material for loan or lease, as it does with fissionable material for power reactors.

Use More Radioisotopes

The AEC's plans to foster increased use of radioisotopes are a little more complex than that worked out for high-level radiation sources. Over the long-range, the Commission wants to encourage construction of reactors designed primarily to produce radioisotopes and for radiation processing. In the meantime, its chief concern is development of a market for the radioisotopes produced as a by-product of the power reactor program.

The plan for drawing industry deeper into the isotopes field does, however, involve a series of "moderate" development contract awards ($10–100,000 apiece) in industries where isotopes have a known or promising use. In addition, AEC hopes to work out jointly-financed projects with industry. The emphasis in both types of arrangement will center on "uses of isotopes we already know something about and also industrial applications discovered in AEC labs but not applied."

Among the industries slated for this kind of nudging are oil, chemicals, steel and others serving broad areas of the economy. Contracts and joint study projects will also be worked out with radiation firms.

"Independent of the contract studies to be administered by the Office of Industrial Development but complementary to them," Fowler disclosed, "is a fission byproducts market analysis being conducted by the Arthur D. Little Co. under contract to General Electric, Hanford Works, Richland, Wash."

This one-year study is aimed primarily at gauging the market for the so-called "waste materials" of the fission process.

Training

Coincidentally, AEC wants to establish a "prototype" training course in applied radiation for industrial engineers at the Oak Ridge Institute for Nuclear Studies. The idea is to carry an industrial technician beyond the basics of applied radiation to at least two weeks' work with radiation equipment.

Isotope Prices Cut

AEC is reducing substantially its prices for cesium-137, strontium-90, promethium-147, cerium-114 and technetium-99. Revised price schedules have been drawn up on the basis of cost savings to be realized this summer when the Fission Product Pilot Plant at Oak Ridge is expected to go on stream for the separation of these isotopes from fission byproducts.

Reactor News

ACF WINS ELK RIVER ASSIGNMENT

ACF Industries won out over General Electric to get the job of building the 22-Mw(e) nuclear power plant at Elk River, Minn. After a close race (NU, March '58, 19), ACF's proposal to "design, develop, construct and test-operate" the 15-Mw boiling reactor and oil-fired superheater was selected by AEC. The Commission announced it will negotiate a "cost-type contract with a maximum ceiling price"; it was a cost-type contract, but without ceiling, that AMF Atomics had sought. AMF's two-year-long negotiations with AEC for a contract ended in failure last fall (NU, Oct. '57, 19; Nov., 19). ACF's ceiling price is understood to be $9.2-million. Construction is now expected to start this spring, with testing to start late next year and full operation in 1960. ACF has chosen Sargent & Lundy as architect-engineer and Maxon Construction Co. as construction contractor.

GE GETS REACTOR JOB FOR TANKER

The country's second nuclear merchant ship may be a 22,500-ton tanker with a General Electric boiling water reactor as motive power. AEC and the Maritime Administration have given GE a contract for a preliminary engineering and design study on converting to nuclear power a new T-5 type tanker now under construction at Ingalls Shipbuilding Co., Pascagoula, Miss. Another contract went to George G. Sharp, Inc., to be ship design agent; GE and Sharp will work together to outline engineering problems, and to work out contract plans and specifications for the reactor and for changes in the ship necessary for installation of a reactor instead of oil-fired boilers. The studies, due in three months, will also provide a basis for cost estimates for the conversion job. The T-5 tanker is designed for a normal speed of 20 knots at 20,000 shaft horsepower. The first nuclear merchant ship, N.S. *Savannah*, will have a Babcock & Wilcox pressurized water reactor; General Dynamics has recently been assigned a long-range development job on a gas-cooled reactor for merchant-ship use.

POOL UNIT FOR B&W AT LYNCHBURG

Babcock & Wilcox is adding a 10-kw pool test reactor to its critical-experiment laboratory at Lynchburg, where it already has two critical-assembly cells operating from one control panel. These zero-power assemblies work only at room temperatures, and B&W is adding a pool reactor because it needs to run experiments at high temperatures. The new unit, to be completed July 1, will also test products of the adjoining fuel-element plant.

EBR-2 FINALLY STARTED

AEC's second experimental breeder, fifth and last of the 1954 five-year-program reactors, entered the construction phase at the Idaho reactor testing station last month, one year late because of Budget Bureau holdback of funds. All the other four reactors in the same program are already completed and operating. The 17.5-Mw(e) EBR-2, for which $29.1-million has been authorized, was developed and is being built by Argonne National Laboratory; H. K. Ferguson Co. is architect-engineer, and Graver Tank & Mfg. Co. is building the containment vessel. Excavation is now under way and the reactor structure will be begun in early summer; EBR-2 is scheduled to operate in 1960.

BURST FUEL ELEMENT AT BORAX-4

The cladding of a fuel element in the Borax-4 boiling reactor experiment at National Reactor Testing Station in Idaho has punctured, NUCLEONICS learns. The reactor is using urania-thoria pellets in aluminum tubes as fuel; the failure was probably a bad seam at the element top. The rupture affords Argonne engineers a long-awaited opportunity to observe behavior of a boiling reactor with some fission products in the system, and the unit has been operated at a new high power density—~50 kw/lit—since the burst. Residual activity is very low and there have been no personnel overexposures. Present plans are to try to locate the failed elements by some logical method.

EBWR RUN UP TO 62 MW

Argonne's Experimental Boiling Water Reactor, designed to operate at 20 Mw(th) and already run up to 50 Mw, last week was taken to a calculated 61.7 Mw(th), which would yield an estimated 15.5 Mw(e) if the plant were not limited by a maximum turbine capability of 6.25 Mw(e); as it is, excess steam was dumped to the condenser. Unit cost of power was brought down to ~ 29½ mills/kwh in the operation. At the experiment's peak, EBWR power was estimated at 64 Mw but this was not calibrated; at that point the reactor still "had some rod left" but ran out of water-delivery capacity: valves were wide open. Replacing the present 4-ft-high core with 5-ft elements would permit EBWR to yield 100 Mw(th) with no other changes, EBWR officials say.

ORR, PCA GO CRITICAL AT OAK RIDGE

ORR, the Oak Ridge Research Reactor, a $5-million high-flux research tool three years a-building, went critical March 21. A combination type having a tank immersed in a pool, ORR is a heterogeneous reactor with a beryllium-reflected core using 90%-enriched, plate-type aluminum-clad fuel elements. It is moderated and cooled with demineralized water. Operated at 20–30-Mw, its average flux is 10^{14} n/cm²/sec. With major design emphasis having been placed on flexibility to permit many kinds of experiments close to the core and on accessibility to the core for high-flux experiments, ORR will permit sizable fuel specimens to be brought into the high-flux region.

Also at Oak Ridge, PCA—Pool Critical Assembly—was installed in the pool of Oak Ridge's Bulk Shielding Reactor—the original swimming pool reactor. Operated independently of BSR, PCA will do zero-power experiments, thus relieving BSR for work in the 1-Mw range.

AEC SPURS CONTROL-ROD DEVELOPMENT

Expressions of interest by private industry to do research and development on finding additional control-rod materials have been sought by AEC. Objective is to provide data for designing control rods using the materials. A firm will be selected to survey existing data on control-rod materials, perform physics calculations and fabricate and irradiate specimens of the materials selected.

WATERTOWN ASKS REACTOR BIDS

Specifications have been issued for building the long-contemplated Watertown Arsenal research reactor and bids were due early this month. Work includes building an 87-ft high, 80-ft-dia container, all shielding and service utilities, and "furnishing and installing a 1,000-kw nuclear reactor." Estimated cost is $1.25–1.5-million.

ROUNDUP

World News

A-Power for Sahara?

Electricité de France, the national power utility, is interested in locating a nuclear power station in the Sahara at Fort Lamy. A special company may be set up jointly by EDF, France's AEC and a development-finance company. Conversations have already been held with General Electric regarding a Vallecitos-type boiling reactor.

Calder-Type Sought in Germany

The six biggest power utilities of Baden-Württemberg, banded together in the syndicate Arbeitsgemeinschaft für Kernkraftwerke (Working Group for Nuclear Power Stations), have invited bids from several U. S. and British manufacturers and Deutsche Babcock & Wilcox for a 150-Mw(e) Calder-type reactor, estimated to cost $71-million. First bids are already in; a site has been chosen but its location is not yet published. A large part of the order is expected to go to Deutsche Babcock & Wilcox.

Germany: Granular-Graphite-Cooled Reactor

A new type of reactor using graphite as both moderator and coolant has been patented (#1,010,203) in Germany by F. A. Henglein, director of the Institute for Chemical Techniques at Karlsruhe Technical University. Elimination of the use of graphite as a structural material is held to eliminate the danger of such accidents as befell Britain's Windscale reactor (NU, Nov. '57, 130; Dec., 43). In the Henglein reactor, fine granular graphite is pumped around the primary between reactor and heat exchanger. The reactor core is rotated in a vertical position (like a rotary furnace) to bring different graphite grains into contact with the channel walls. Reactivity can be accurately adjusted by the amount of graphite in the core; this is said to afford an extra safety medium in case control rods should fail. A somewhat similar concept for a dust-fueled reactor was unveiled at last month's Nuclear Congress (*see p. 22*).

Iron Curtain Items

A delegation of Polish atomic experts has spent three weeks touring India, and signed an agreement on cooperation in nuclear science covering exchange of students and technicians, materials and information. Two Polish scientists are to spend a year at the Bombay reactor, and India will send scientists to Warsaw when the Polish research reactor is started up this spring. . . . Russia claims the world's first stereobetatron, placed in operation at Tomsk Polytechnic Institute. A combination of two betatrons, it produces two crossing beams of electrons; this, it's said, permits study of their interactions, gives stereophotos that can be used in industrial quality control and for locating defects with precision. . . . Red China has completed its first cyclotron, of 25 Mev; and its first reactor, a heavy-water 7-Mw(th) research reactor, is "basically complete," according to Radio Peiping.

British Briefs

A 100-acre site at Sizewell in Suffolk County on England's east coast has been recommended as the location of a future nuclear power station. . . . As a result of lessons learned from the Windscale accident, new instrumentation is being installed on Bepo at Harwell. The 5-Mw(th) radioisotope-producing reactor, Britain's first large one (1949), has been shut down for periodic overhaul since December. The new instruments will be mainly temperature recorders and neutron-flux indicators; they imply no inherent danger in Bepo, AEA spokesmen stressed. . . . General Electric Co. of England opened a new beryllium research lab, part of its expanding nuclear research program that has seen the company double its research staff in the last 18 months.

Grenoble Research Center Opened

The Centre d'Etudes Nucléaire de Grenoble (Grenoble Nuclear Study Center) has been opened by France's AEC (NU, Nov. '56, R9) as an adjunct to the Saclay research center. The lab at Grenoble will be used primarily for study in solid state physics, magnetism, fluid heat transfer, and behavior of reactors and of neutrons. Grenoble will also be a training center.

Egypt U-Prospecting in Syria, Yemen

Egypt's AEC is sending prospecting teams to Syria and Yemen to search for uranium in these two countries now linked with Egypt in the new United Arab Republic. Both are said to be rich in iron, chromium and uranium.

Danatom Set Up in Denmark

An independent institution for applied nuclear research, Danatom, has been established by the Danish Academy of Technical Sciences, the largest industrial firms, the electric utilities, and the shipowners. Already set up by Danatom are working groups on power reactors, ship-propulsion reactors, welding techniques and electronic equipment.

Saunders-Roe Plane Sought by U. S. Navy

The U. S. Navy has approached Britain's Saunders-Roe airplane builders about using a 140-ton "Princess" flying-boat as a reactor test bed. The three existing Princesses have been in mothballs three years, waiting for an engine big enough to be developed. The U. K. had also been considering using a Princess in its own atomic plane program (NU, July '57, 27). The *London Daily Mail* says a U. S. deal is "99% certain."

NRU Refueled While in Operation

NRU, Canada's big new research reactor, became the world's first reactor to be refueled while in operation. The unit's charging machine passed its first fully operational test a month ago, successfully changing uranium rods while critical. Towering 43 feet above the rails on which it travels atop the reactor, the 240-ton charging machine can be positioned with an accuracy of 0.01-in. It requires four control panels, and contains 17 pumps to handle its triple-layer cooling system: heavy water cools the fuel elements, light water cools the D_2O, and a refrigeration system cools the light water.

NDA Plan Would Pool U. S., Belgian Research

A new type of proposal under the demonstration program, involving foreign participation, has been made to AEC by Nuclear Development Corp. of America in connection with its steam-cooled reactor concept (NU, Feb. '58, 24). Under the plan, Belgian power utilities would participate in research-development work together with NDA and East Central Nuclear Group; they would contribute their know-how to the development effort but would be free to make independent decisions whether and when to build a plant of their own in Belgium.

News in Brief

Chemical Processing Conversion Charges Set

AEC has published the prices it will charge for converting the products of chemical reprocessing of reactor fuel into forms for which Commission prices have previously been set. When it announced last year (NU, April '57, 19) that it will provide interim reprocessing service until industry takes over, AEC said its reprocessing system would yield purified nitrate salts of uranium and plutonium, with additional charges to be set for conversion to UF_6 and Pu metal, the forms for which AEC prices have been established. The additional charges are: 1. Conversion of purified low-enrichment uranyl nitrate (5% or less by weight of U^{235} in total U) into UF_6: $5.60/kg of contained U. 2. Conversion of purified high-enrichment uranyl nitrate (more than 5% by weight of U^{235}) into UF_6: $32/kg of contained U. 3. Conversion of purified plutonium nitrate into Pu metal: $1.50/gm of contained plutonium.

Dempsey of JCAE Dead; Aspinall Succeeds

Rep. John J. Dempsey, New Mexico Democrat, died March 11, aged 78. A former governor of New Mexico, he served seven terms in the House (1935–41 and since 1951) and was a member of the Joint Committee on Atomic Energy since January 1955. The Democrats have named Wayne Aspinall of Colorado to succeed him. Aspinall, in the House since 1949, is expected, like Dempsey, to watch out for Western uranium interests.

1957 Uranium Production Figures Out

Domestic U-reserves on Dec. 31, 1957, were estimated at 78-million tons, up from 60-million a year earlier, AEC has disclosed. 53-million tons of it is in New Mexico, 9-million in Wyoming, 5.7-million in Utah, 4-million in Colorado, and the rest spread through ten states and Alaska. Ore receipts for 1957 totaled 3,676,000 dry short tons, with the monthly rate increasing from 269,000 tons in January to 381,000 in December. Ore fed to process totaled 3,575,000 tons with an average of 0.27% U_3O_8; ore stockpiled as of Dec. 31 was 2-million dry tons. $2.45-million was paid by AEC in 1957 in initial production bonuses. Concentrates received at AEC's Grand Junction, Colo., depot totaled 8,494 tons of U_3O_8, with an additional 146 tons produced from processing Florida phosphates, treating Idaho euxenite, and reprocessing refinery residues.

Industry Briefs

Columbia-National Corp. has shipped its first lot of reactor-grade zirconium to AEC for use in the Navy and other A-power programs. The company has a $22.75-million contract to supply 3.5-million lb Zr over five years. . . . **Yankee Atomic Electric Co.** is seeking state approval for $4-million temporary financing for its Rowe, Mass., reactor plant. The new money would bring Yankee's total capitalization to $8-million. Arrangements have been made, Yankee says, for permanent financing of the plant's $57-million cost by placing $20-million first mortgage bonds with a group of life insurance firms, $17-million unsecured borrowings from a group of commercial banks, and $20-million from capital stock of the sponsoring companies. . . . **Isotope Products Ltd.**, which has become an 80%-owned subsidiary of Curtiss-Wright, is now known as Canadian Curtiss-Wright Ltd. It is assuming responsibilities for all C-W activities in Canada; its sales and service responsibilities in the U. S. are now consolidated in the Electronics division at Carlstadt, N. J. . . . **Isotopes Specialties Co. Inc.** of Burbank, Calif., is getting an AEC license to collect nuclear waste materials and dispose of them at sea in at least 1,000 fathoms of water. Three other firms currently do this work: Crossroads Marine Disposal, Boston; Reed Curtis Nuclear Industries, Culver City, Calif.; and Nuclear Engineering Co., San Francisco. . . . **Sawyer Petroleum Co.** of Los Angeles is acquiring one of the largest-known thorite deposits on the continent, located in Beaverhead county, Montana, and will produce thorium concentrates. More than 90% of the thorium now consumed in the U. S. and Canada is imported from South America. . . . Production of reactor fuel materials has begun at the new Erwin, Tenn., plant of **Davison Chemical Co.**, a division of W. R. Grace & Co. The plant can produce uranium and thorium metal, oxides and alloys.

JCAE Sets Waste-Disposal Hearings

April 28–May 6 has been set as the date for public hearings on industrial radioactive waste-disposal problems by the Joint Committee's Special Subcommittee on Radiation under Rep. Holifield.

AEC Briefs

The first U. S. shipment of enriched uranium for a French reactor, made last month, consisted of 35 20%-enriched fuel rods containing 5.51 kg of U^{235}. Made by Babcock & Wilcox and valued at $118,000, they will be installed in Mélusine, the pool reactor at the Nuclear Study Center in Grenoble. . . . AEC signed contracts for sale of 2,000 kg natural uranium in the form of aluminum-clad rods for the subcritical reactor at Cagliari U., Italy; and one ton of heavy water (in addition to 11 tons previously sold) to Australia for the HIFAR reactor at Lucas Heights. . . . A public meeting will be held April 15 by AEC in connection with its review of its patents program, to hear comments from interested parties. It will start at 10 A.M., 1717 H. Street NW.

U. S. Shippers Invited to Run Savannah

American shipping firms have been invited by AEC and the Maritime Administration to speak up if they are interested in becoming operators of N.S. *Savannah*, the first nuclear merchant ship. The invitation points out that the training program already set for the crew—25 officers and 84 men—requires licensed engineering officers to report Sept. 1, and that an operating contract must be concluded by June 1 this year.

Malan to Build C-Stellarator

A $1,845,000 contract for construction of the C-Stellarator buildings at Princeton has been awarded Malan Construction Co. by AEC. Malan was lowest of 16 bidders. Construction, to start at once, is to be completed within a year; the big fusion-power experiment itself is to operate in late 1960 or early 1961. Commonwealth Associates Inc. won a $370,000 architect-engineering contract.

Contract Let for Plane Test Pool

At the ANP area at the Idaho testing station, W. R. Cahoon Co. of Pocatello, low bidder among thirteen firms at $773,047, was awarded a contract for construction of the Shield Test Pool Facility. The two combined one-story buildings—one containing the pool facility, the other controls and equipment—will be used for testing prototypes or mockups of nuclear aircraft incorporating shield materials and configurations for crew protection.

75 Fusion Papers Among 1550 Filed for Geneva

Twenty-nine nations have submitted 1550 technical abstracts—with more to come—for the Second International Conference on the Peaceful Uses of Atomic Energy at Geneva in September (NU, Aug. '57, 23).

A United Nations spokesman said a total of about 2500 papers will be offered before the "effective" deadline—August 1. Six hundred of these will be accepted for reading at the conference.

One very striking difference from the 1955 conference is the large number of papers on thermonuclear power. What was only mentioned then in Homi Bhabha's opening speech has now blossomed into a major fraction of the total presentation. Some 75 papers have already been offered in this area and another 60 are expected from Russia. Of the 75 abstracts already in the UN's hands, 45 are from the U. S., about six from Britain and a sprinkling from the smaller fusion programs around the world.

The titles of the U. S. papers provide the first hint as to the nature of approaches to fusion power other than the pinch effect: radio frequency thermonuclear machines; study and use of rotating plasma; the triaxial pinch; summary of Pyrotron program (University of California Radiation Laboratory); and production and utilization of high-flux beams of energetic neutral particles, among others.

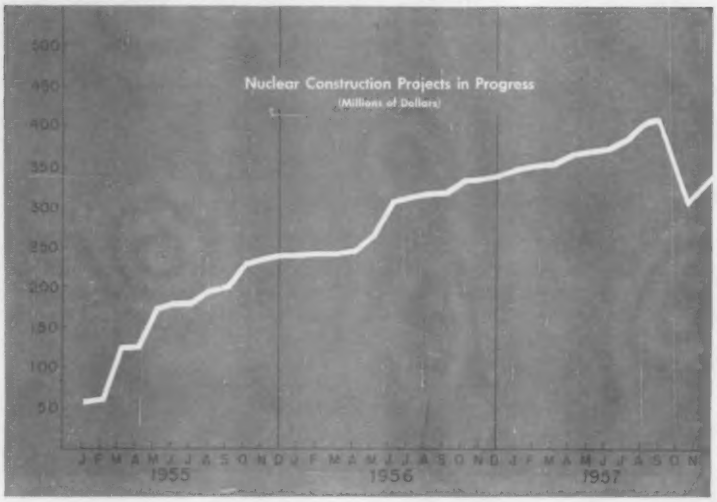
Apparently, feeding energy into plasmas by means of electromagnetic waves and handling high-energy particles as neutral entities are significant parts of the fusion program in the U. S.

Fusion Exhibits, Too

UN sources predicted that the high number of fusion papers would be supplemented by fusion exhibits from all three nations with major programs—U. S., Britain and the U. S. S. R.

Of the 1550 abstracts submitted through the end of March, the U. S., Britain and France were the only nations offering more than 100 (638, 162 and 198, respectively). Russia, however, was expected to offer a substantial list. The formal deadline for filing is June 1, but papers will be accepted until Aug. 1. NUCLEONICS will carry details next month.

NUCLEONICS Statistics of the Month



	Latest month	Month ago	Year ago
Nuclear Contracts*—			
Contracts awarded for federal projects ($10³)	2,455	2,980	1,091
Proposed construction, privately-owned ($10³)	22,500	0	0
Contracts awarded, private work ($10³)	0	0	5,400
Backlog of private projects ($10⁶)	269	247	175
Access Permits†—			
Access permits issued	12	13	28
Total access permit holders	1,402	1,402	1,208
Isotope Use†—			
Applications for isotope use	328	465	425
Cumulative total of isotope users	3,512	3,469	3,822
Oak Ridge National Laboratory shipments	1,162	1,243	1,068
Public and private export shipments	252	91	151
Employment††—			
AEC employment	6,787	6,783	6,654
Construction and design contractors' employment	10,181	11,286	14,118
Total operating contractors' employment	100,067	99,073	93,974
Production workers	50,299	50,280	50,243
Research and development employees	43,651	42,736	38,043
Miscellaneous workers	6,117	6,057	5,688

	Operating	Building	Contracted
U. S.-built Reactors‡—			
Power, domestic	1	5	8
Power, for export	0	1	5
Power experiments and pilot plants	7	3	3
Military and naval	5	20	13
Research and test, domestic	43	24	38
Research and test, for export	7	14	4
Foreign-built Reactors‡—			
Power, domestic	4	24	12
Power, for export	0	0	2
Research and test, domestic	25	17	8
Research and test, for export	4	8	1

* From *Construction Daily*, a McGraw-Hill periodical †From AEC ‡ NUCLEONICS figures

New Instrument News

Operation and Selection of "RCLiac" Scaler-Analyzers

General Description

The "RCLiac" scaler-analyzers are innovations to nuclear data processing. Nuclear detector pulses are processed and quantized in total or in spectra.

Operation and Application

Two basic modes of operation yield extensive applications in the laboratory. Gross counting, the scaler mode of operation, affords events-per-interval-of-time or time-per-event analysis. Time intervals or event totals may be preset. Simple applications in this mode of operation are: half-life determination, pulsed reactor response, fast-neutron velocity distribution, and other similar studies. With the aid of an automatic sample changer, as many samples as there are channels can be counted, automatically.

The spectrometry mode of operation allows background reduction, smaller tracer doses, isotope identification, complex spectral distribution analysis and other related analyses.

With their inherent versatility of operation and application the RCLiacs are believed to be destined to become as universally accepted in the nuclear field as the oscilliscope is in the electronic field.

Readout

The RCLiacs have two basic readout modes, "Curve" and "Number". "Curve" readout plots graphically the total count recorded in each channel. "Number" readout displays the arithmetic total of counts received in each channel in decimal Arabic form. Both RCLiac models have switch-selected "Curve-Number" readout displayed on a cathode-ray tube which presents a photographic image for rapid and accurate recording of data for permanent reference.

Design

Reliability, precision and ease of operation have been designed into the RCLiacs. Design features which contribute to these parameters of operation are: 95% transistorization affording greater reliability and lower power requirements, printed circuitry throughout and modular construction affording unique adaptions for specific situations. Yet the RCLiacs are remarkably small in size and weight, actually portable.

Selection

Selection of your RCLiac should be based primarily on your facility's basic research requirements. For the modest laboratory the RCLiac-32 should be considered, while larger installations may require the RCLiac-128. The RCLiac-128 has four times the range of the RCLiac-32, affording a greater energy range in the spectrometry mode and a greater range of operation in the gross counting mode.

The finest spectrometry instrument now in use is the RCL 256-channel analyzer, the most widely accepted instrument for pulse-height analysis.

Your RCL representative can offer excellent counsel and help you in the proper selection of the right RCLiac for you. Write today for more detailed information on the RCLiacs and a list of representatives near you.

Introducing

RCLiac-32 and 128

transitorized multi-channel scaler-analyzer data processing systems

One instrument that performs all operations from detection to qualitative or quantitative analysis. All counting and analytical operations from simple gross counting through scintillation spectroscopy and pulse-height analysis can be accurately and rapidly processed by the RCLiacs. Representative features:

- Six plug-in modules
- Super-stable H.V. supply, continuously variable from 500 to 1500 volts
- Completely transistorized linear amplifier
- Preset time from 0.1 second to several days
- Preset count from 10 to several billion
- Maximum zero drift: ½ channel per day on RCLiac-32
  1 channel per day on RCLiac-128
- Maximum input pulse rate: 50,000 pps.
- Data stored in decimal form
- One million count capacity per channel
- Readout is "live" during accumulation in either "curve" or "number" mode
- Instant, permanent recording of data by use of Polaroid camera
- Outputs available for strip chart recorder and digital printer.

Personal Demonstration

If you did not see the remarkable RCLiac-32 at the Atom Fair, write or call RCL collect today. Arrangements will be made for you to receive a personal demonstration at your convenience.

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NUCLEONIC PARK, SKOKIE, ILLINOIS

Radiation Counter Laboratories, Inc. Dept. 148
Nucleonics Park, Skokie, Ill.

Gentlemen,

Please send me information on the ☐ RCLiac-32, ☐ RCLiac-128, ☐ RCL's 256 Channel Analyzer.

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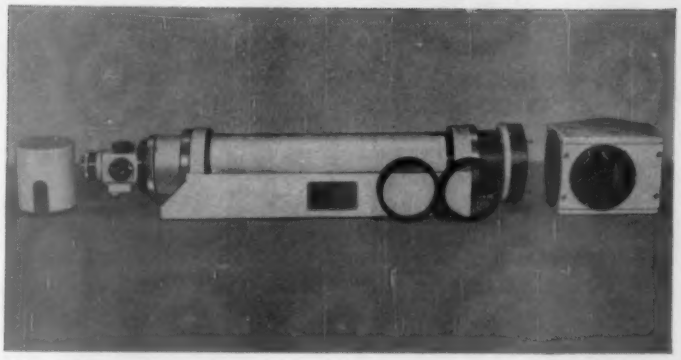
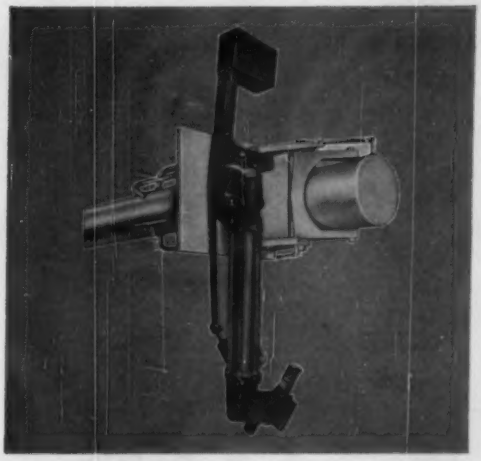


Problem To align radar antennas with extreme accuracy.

Solution Kollmorgen 30X Collimator.
Measures within a pencil's width at a mile.



Problem Remote viewing in the presence of harmful radiation, heat, pressure, water or toxic gases.

Solution Kollmorgen Wall Periscopes with non-browning optics, corrosion-resistant materials, 180° scanning.

Kollmorgen instruments like these are bridges between the eye and the invisible.

The various instruments on this page all have one purpose in common—they allow the observation and measurement of objects which it would otherwise be impossible to see in detail. In bunkers, under water, in the absence of light, in the presence of radioactivity and under many other adverse conditions, Kollmorgen remote viewing instruments have brought the eye of the observer to the heart of his problem.

A letter to us with a simple sketch illustrating your remote viewing problem will place one of America's most respected and versatile designers and manufacturers of optical instruments at your service. For more information write Department 114.

Problem Detailed, long-range observation at sea under varying weather conditions.

Solution Kollmorgen 20X, 120 Ship Binocular. Wide, bright field. Hermetically sealed, super lightweight.

See special Shippingport story in this issue . . . Underwater Observation Equipment supplied by Kollmorgen.

Problem Internal inspection of inaccessible areas of tubing, long bores, machinery, engines, aircraft structures.

Solution Zeiss-Kollmorgen Self-illuminating Borescopes. Diameters from .100", lengths to 45 feet. Bright, clear field.

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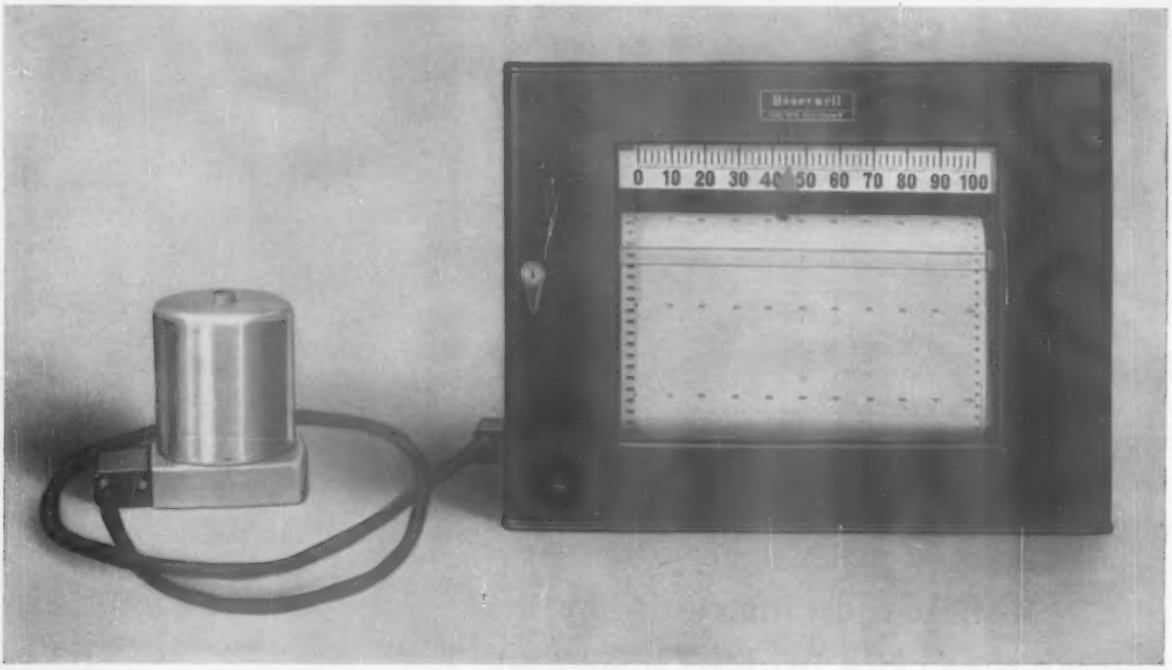

Proved-In-Use
BROWN ELECTROMETER
for recording radiation data

Valuable aid in chemical nucleonics, this instrument records currents as small as 10^{-15} ampere . . . useful in isotope tracer studies, nuclear fuel reprocessing, and similar atomic investigations.

THE exceptionally high sensitivity of the Brown Electrometer makes it ideal for a wide range of atomic radiation measurements. Use it with beta gages, ion chambers, photoelectric scintillation counters or other detecting elements which produce minute currents. It is excellent, too, for use in mass spectrometers . . . in spectroscopic analysis using vacuum phototubes.

The Electrometer consists of a preamplifier head connected to a special *ElectroniK* recorder. Full scale range is 10^{-13} amperes for maximum sensitivity model . . . can be changed by 10 or 100 to 1 by means of a range switch. System accuracy is approximately 1% of scale. Zero drift should not exceed 0.3 millivolt per day. Input resistor is 10^{11} ohms for highest current sensitivity . . . also supplied in values down to 10^5 ohms.

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The Brown Electrometer, proved by years of use in leading atomic installations, is a valuable asset in any lab doing nuclear studies. Call your local Honeywell field engineer for a discussion of your application . . . he's as near as your phone.

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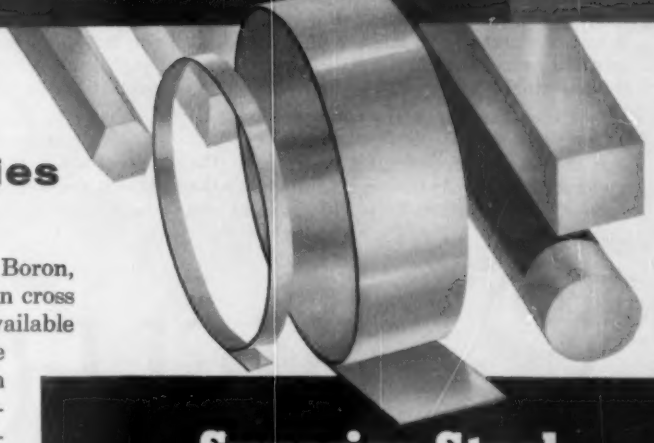

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As for tomorrow — the concept is breathtaking. The APPR can literally change the face of the globe, bringing warmth to the frigid Arctic and Antarctic . . . power to the undeveloped areas of the world . . . light and civilization to primitive deserts and jungles.

Yet "packaged" nuclear power is only one of the tremendous growth areas of the nucleonics industry. So it's important to remember that Business Publications Standard Rate and Data Service in Section 101A lists *only one* publication as servicing and selling the booming nuclear industry — and that is Nucleonics. Circulation is growing rapidly — over 20,000 in 1958!

Talk to your Nucleonics representative *today* about your marketing problems or sales potentials in the important nuclear field. It's a rich market now, an unlimited market in the future!

NUCLEONICS

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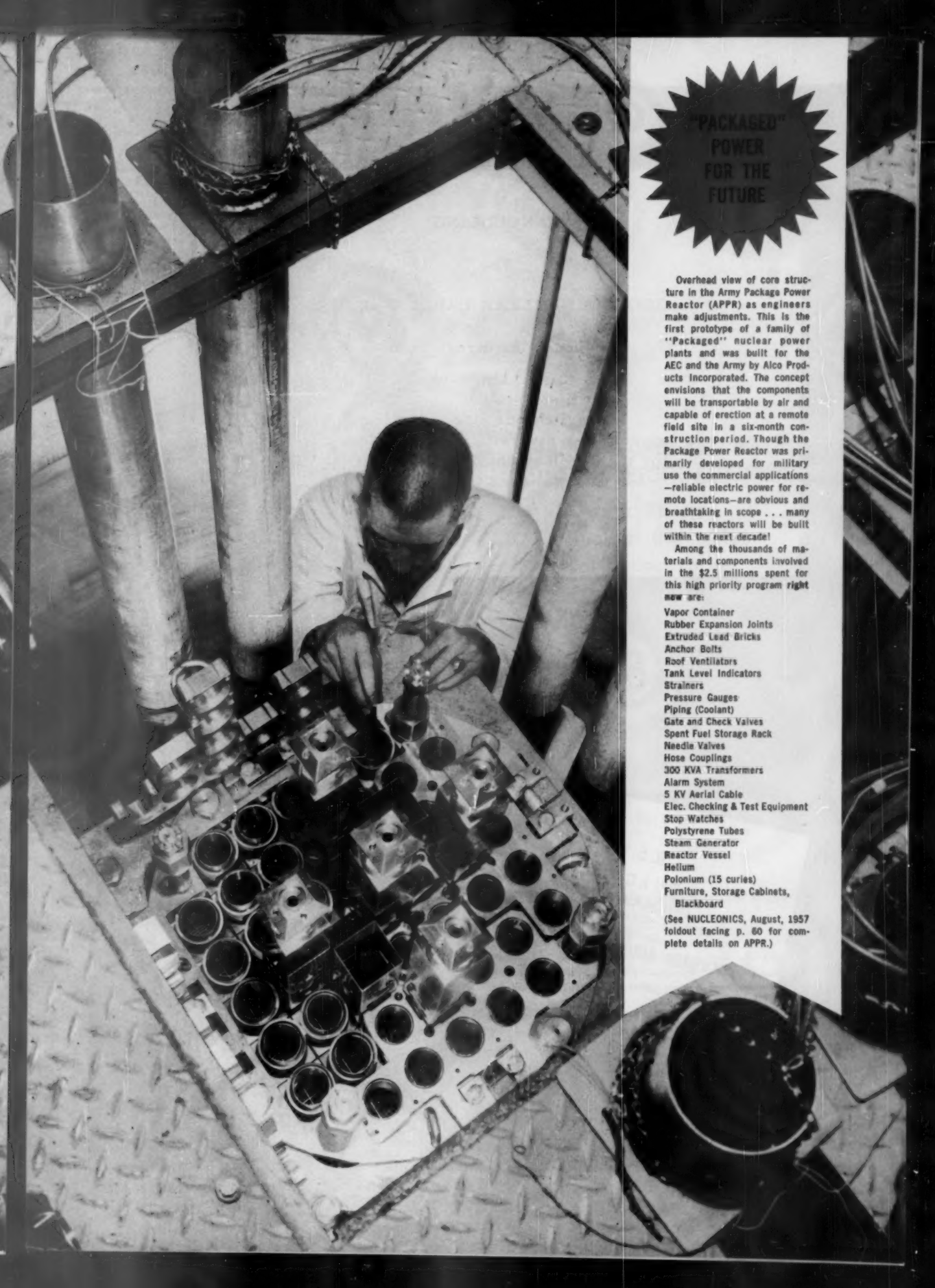

"PACKAGED" POWER FOR THE FUTURE

Overhead view of core structure in the Army Package Power Reactor (APPR) as engineers make adjustments. This is the first prototype of a family of "Packaged" nuclear power plants and was built for the AEC and the Army by Alco Products Incorporated. The concept envisions that the components will be transportable by air and capable of erection at a remote field site in a six-month construction period. Though the Package Power Reactor was primarily developed for military use the commercial applications—reliable electric power for remote locations—are obvious and breathtaking in scope . . . many of these reactors will be built within the next decade!

Among the thousands of materials and components involved in the $2.5 millions spent for this high priority program right now are:

Vapor Container
Rubber Expansion Joints
Extruded Lead Bricks
Anchor Bolts
Roof Ventilators
Tank Level Indicators
Strainers
Pressure Gauges
Piping (Coolant)
Gate and Check Valves
Spent Fuel Storage Rack
Needle Valves
Hose Couplings
300 KVA Transformers
Alarm System
5 KV Aerial Cable
Elec. Checking & Test Equipment
Stop Watches
Polystyrene Tubes
Steam Generator
Reactor Vessel
Helium
Polonium (15 curies)
Furniture, Storage Cabinets, Blackboard

(See NUCLEONICS, August, 1957 foldout facing p. 60 for complete details on APPR.)

ANNOUNCING

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Inquiries invited.

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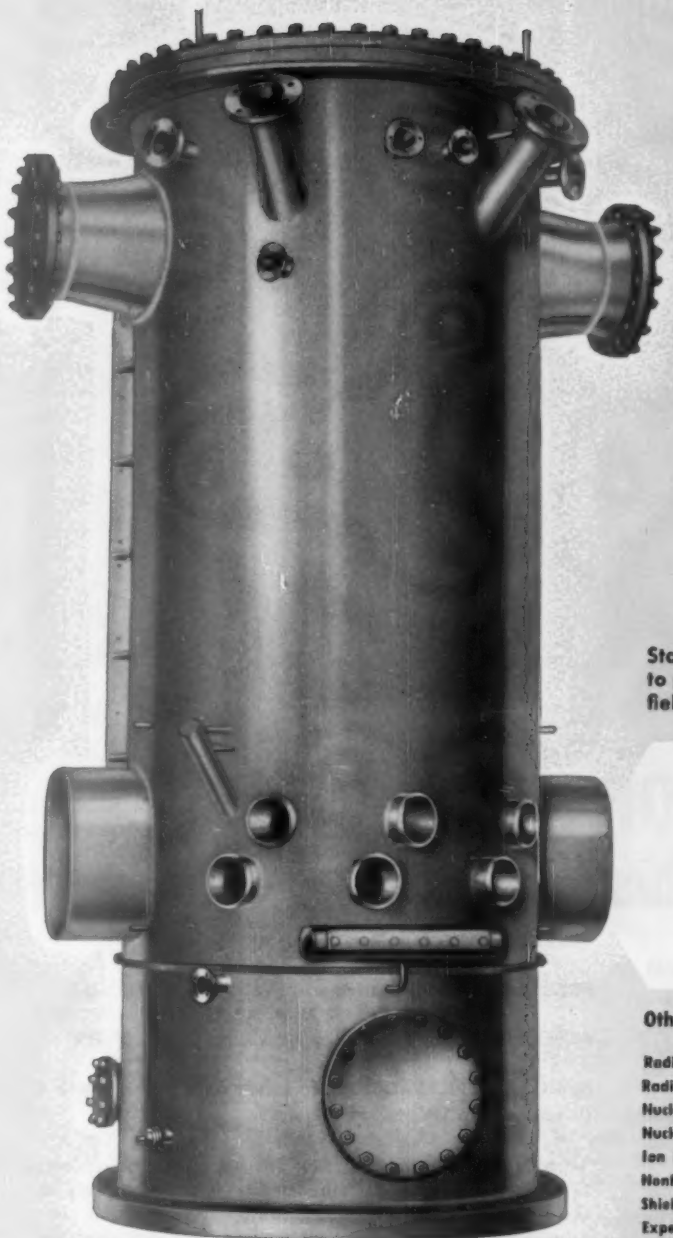

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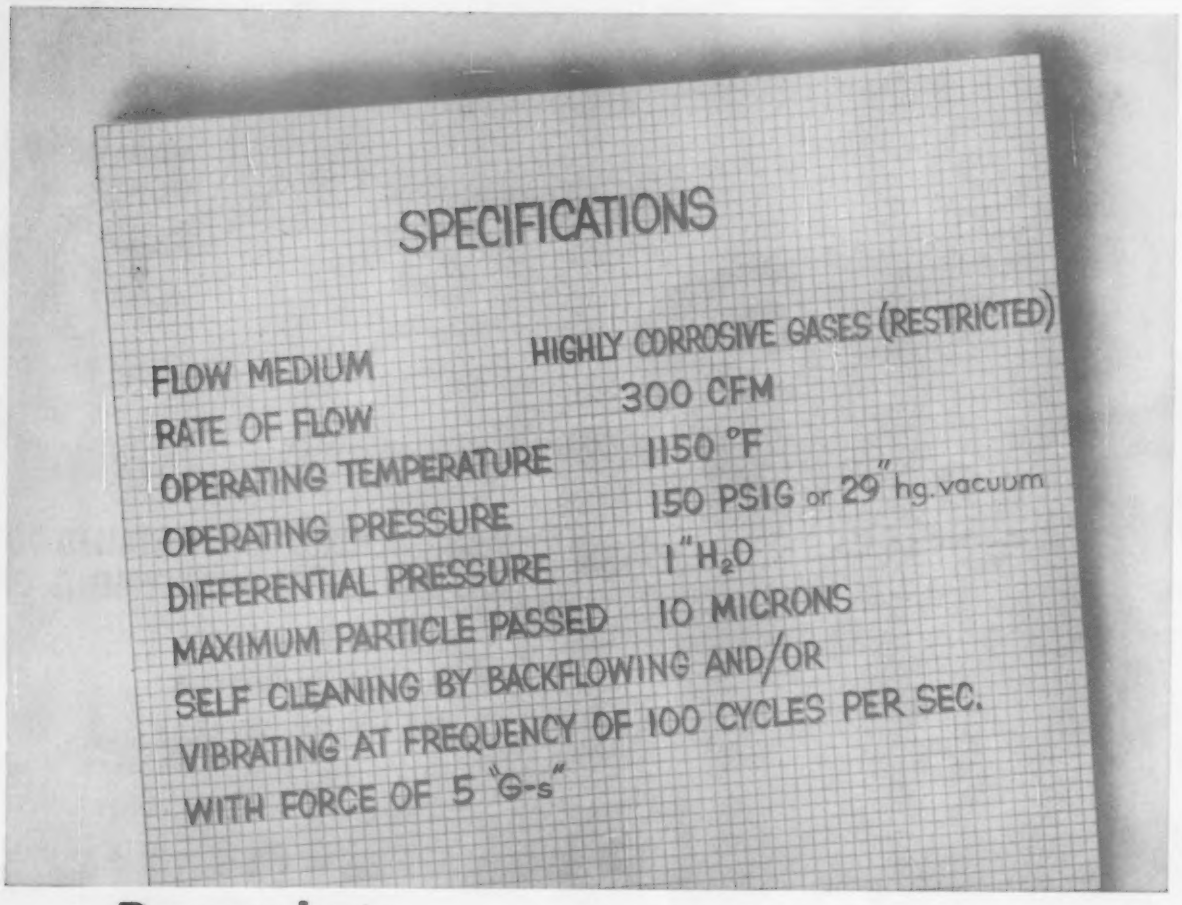
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FLOW MEDIUM HIGHLY CORROSIVE GASES (RESTRICTED)
RATE OF FLOW 300 CFM
OPERATING TEMPERATURE 1150 °F
OPERATING PRESSURE 150 PSIG or 29" hg. vacuum
DIFFERENTIAL PRESSURE 1" H_2O
MAXIMUM PARTICLE PASSED 10 MICRONS
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WITH FORCE OF 5 "G-s"

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TEMPERATURES: from —420° to 1200° F.

PRESSURES: from a nearly perfect vacuum to 6,000 p.s.i.

RATES OF FLOW: from drop by drop to thousands of GPM.

DEGREES OF FILTRATION: from submicronic to 700 microns (in various media).

This complete filtration service, for the toughest problems in nuclear and chemical applications, is available only at Purolator. Purolator's engineers are ready to work on your requirements. If you have an *urgent* need for specially designed filtration systems, call Jules Kovacs, Vice President in charge of Research and Development and Product Application . . . or send him the details of your application.

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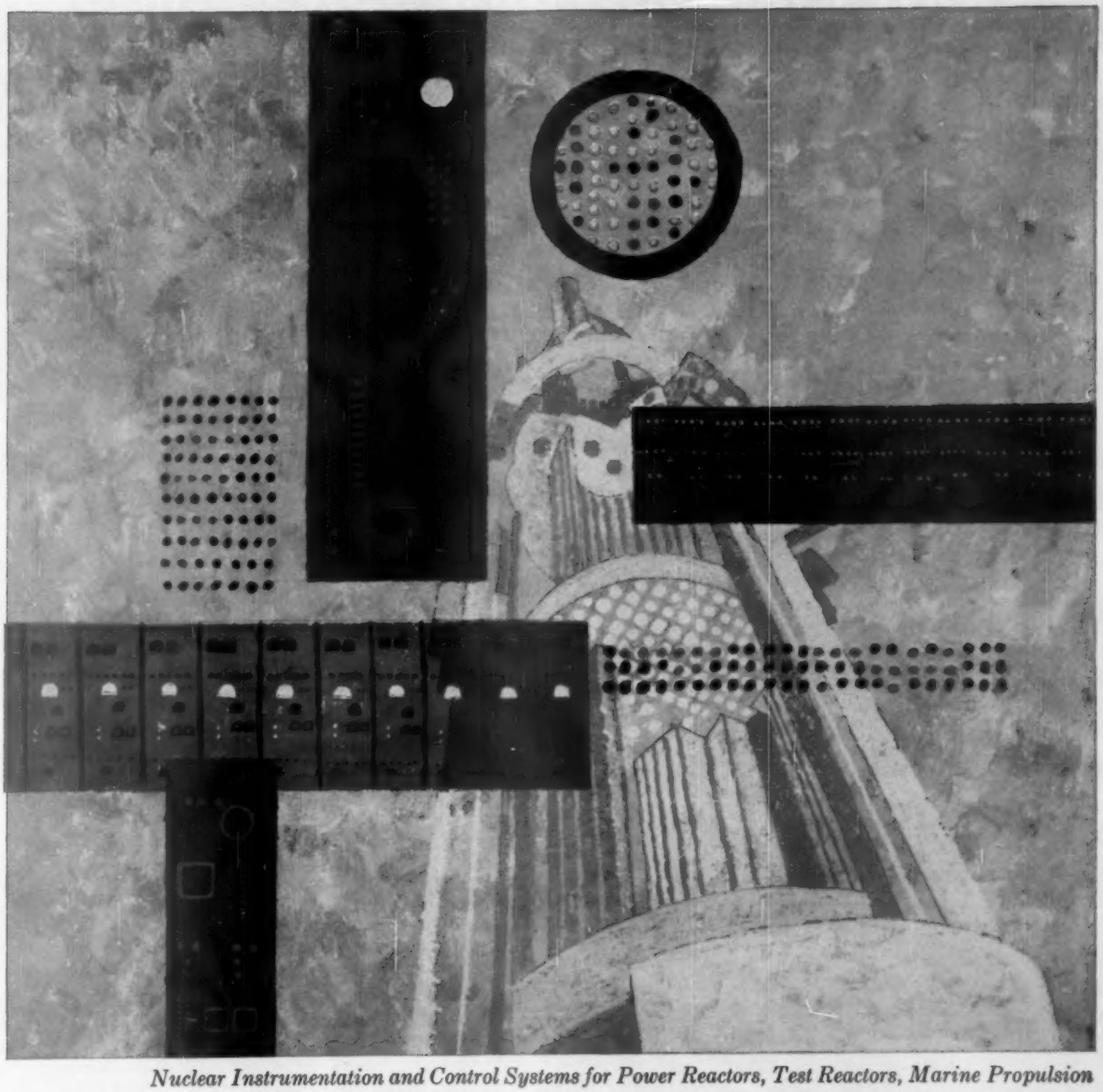


Nuclear Instrumentation and Control Systems for Power Reactors, Test Reactors, Marine Propulsion

from a decade of nuclear pioneering . . .

Instrumentation for Every Atomic Need

Plowback of Earnings into research, development and engineering has been an established policy at Westinghouse since its founding. This research program led to the development, over 10 years ago, of extensive atomic studies to find the most practical techniques for harnessing nuclear power. The experience gained in early atomic programs has made this field an established *industry* at Westinghouse.

Coupled with this research leadership, years of engineering, design and manufacturing know-how enable Westinghouse to produce the only *complete line* of nuclear control and instrumentation equipment.

Westinghouse engineers have the practical nuclear experience to help you—whether your project be commercial power plant, marine propulsion or test reactor.

For further information and a copy of our nuclear control and instrumentation booklet (B-7233), write to Westinghouse Electric Corporation, Nuclear and Marine Sales, P.O. Box 868, Pittsburgh 30, Pa. J-60953

YOU CAN BE SURE...IF IT'S Westinghouse

how different will you dare to be...

ALLEGHENY LUDLUM

PIONEERING on the Horizons of Steel

Warehouse stocks carried by all Ryerson steel plants

All of these products represent big industries: some old, some very new—but all growing, changing and bright with promise. Someone dared to be different.

Why? Because people wanted to do things differently and better . . . travel, live, build, talk, see, listen, protect, defend. And because the special alloy steels and other new metals that could trigger such advances were *available.* That was the big essential, because you can design only as far as available materials will let you go.

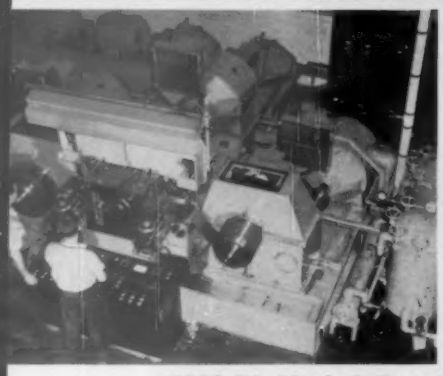
Many of these special materials are Allegheny Ludlum pioneering developments: stainless and super high-temperature steels; grain-oriented silicon steels and special electrical alloys; titanium, zirconium, carbides and other special-property metals.

It is our continuing job to research and develop such materials. *And much more important*: make them available to you in the shapes, forms, sizes and volume you require, high in quality and uniform in properties. Let us work with you.

Allegheny Ludlum Steel Corporation, Oliver Building, Pittsburgh 22, Pennsylvania.

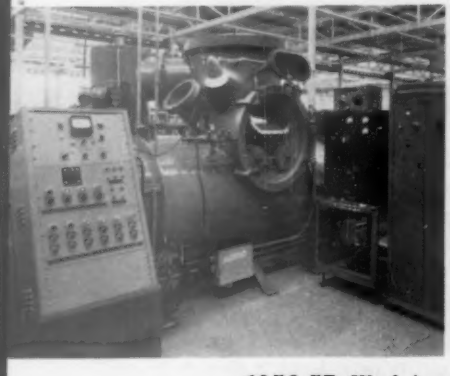
Stainless and high-temperature, electrical and tool steels; magnetic materials and sintered carbides WSW 6622-A

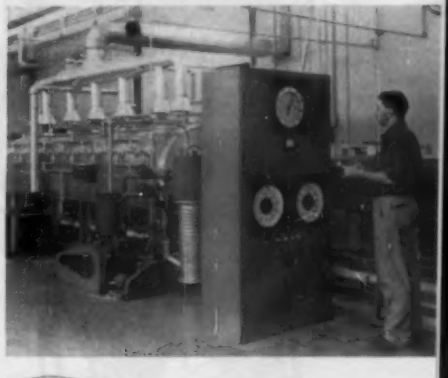
Keeping Pace with Nuclear Progress



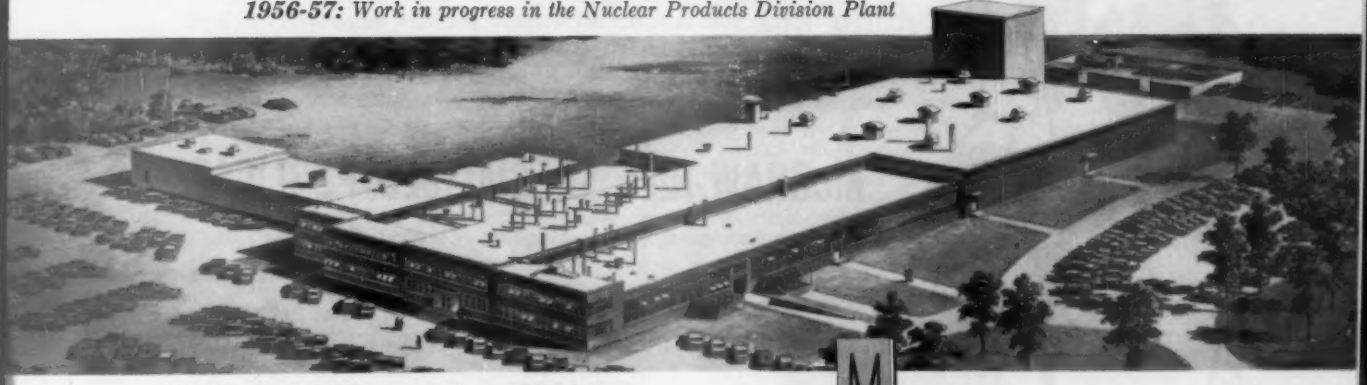
1952-54: *Metals & Controls Corporation fabricated nuclear fuel elements in its General Plate Division*

1955: *Building the new 36,000 sq. ft. plant for the Nuclear Products Division, Metals & Controls Corporation*





1956-57: *Work in progress in the Nuclear Products Division Plant*



1958: *Present 140,000 sq. ft. plant of M&C Nuclear, Inc., showing the 12,000 sq. ft. research and development laboratory at left, and new 65-ft-high core-assembly area at right.*

M&C NUCLEAR, INC.

P. O. BOX 898 ATTLEBORO, MASSACHUSETTS

your

two

best

friends...

"the man ahead"

and

"the man behind"

That man just ahead of you hopes you'll take his job away from him. He's plain selfish about it . . . that way you push him up the ladder, too.

The fellow right behind you, what about him? He's another good friend. Just help make him more capable of capturing your present spot . . . see, now he's pushing you!

How can you serve yourself better than you ever have before? By upgrading your own job performance. By learning all you can about other functions of your company's business. By putting today's problems together with tomorrow's promises . . . and becoming more and more knowing about both, right here in the high-utility pages of this one specialized publication.

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Look ahead, read ahead, get ahead. Live this secret. Share it. After you've read this issue so satisfyingly, hand it over to that man one step below. Show him how much there's in it for him, too. A few issues from now, we'll bet he looks you in the eye and says, "Thanks, friend. I just got my own subscription."

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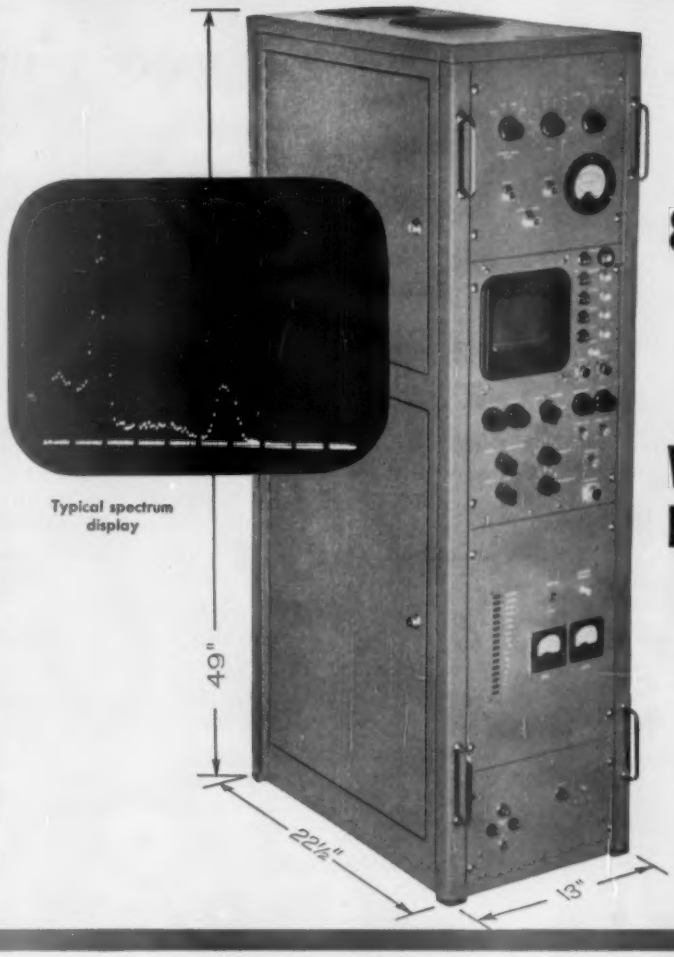

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BENDIX OFFERS THE CHALK RIVER

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smallest 100-channel pulse height analyzer available

This is the analyzer recently developed by Atomic Energy of Canada, Ltd. The Cincinnati Division of Bendix Aviation Corporation has been licensed to manufacture and market the analyzer in the United States. Magnetic-core storage is provided for 100 fixed adjacent channels, each having widths from 0.03 to 0.3 volts. With the biased-off window amplifier and a 30-volt spectrum, 1,000-channel analysis can be performed. Average dead-time is 85 microseconds. Design considerations have been discussed in the following references: F. S. Goulding, "KICKSORTER DEVELOPMENTS AT CHALK RIVER" in *Multi-channel Pulse Height Analyzers*, National Research Council, publication 467, pgs. 86-94; F. S. Goulding, "SOME TRANSISTOR CIRCUITS USED IN MAGNETIC CORE TYPE KICKSORTER", 1956 IRE Convention Record, part 9, pgs. 76-81. Cincinnati Division, 3130 Wasson Rd., Cincinnati 8, Ohio.

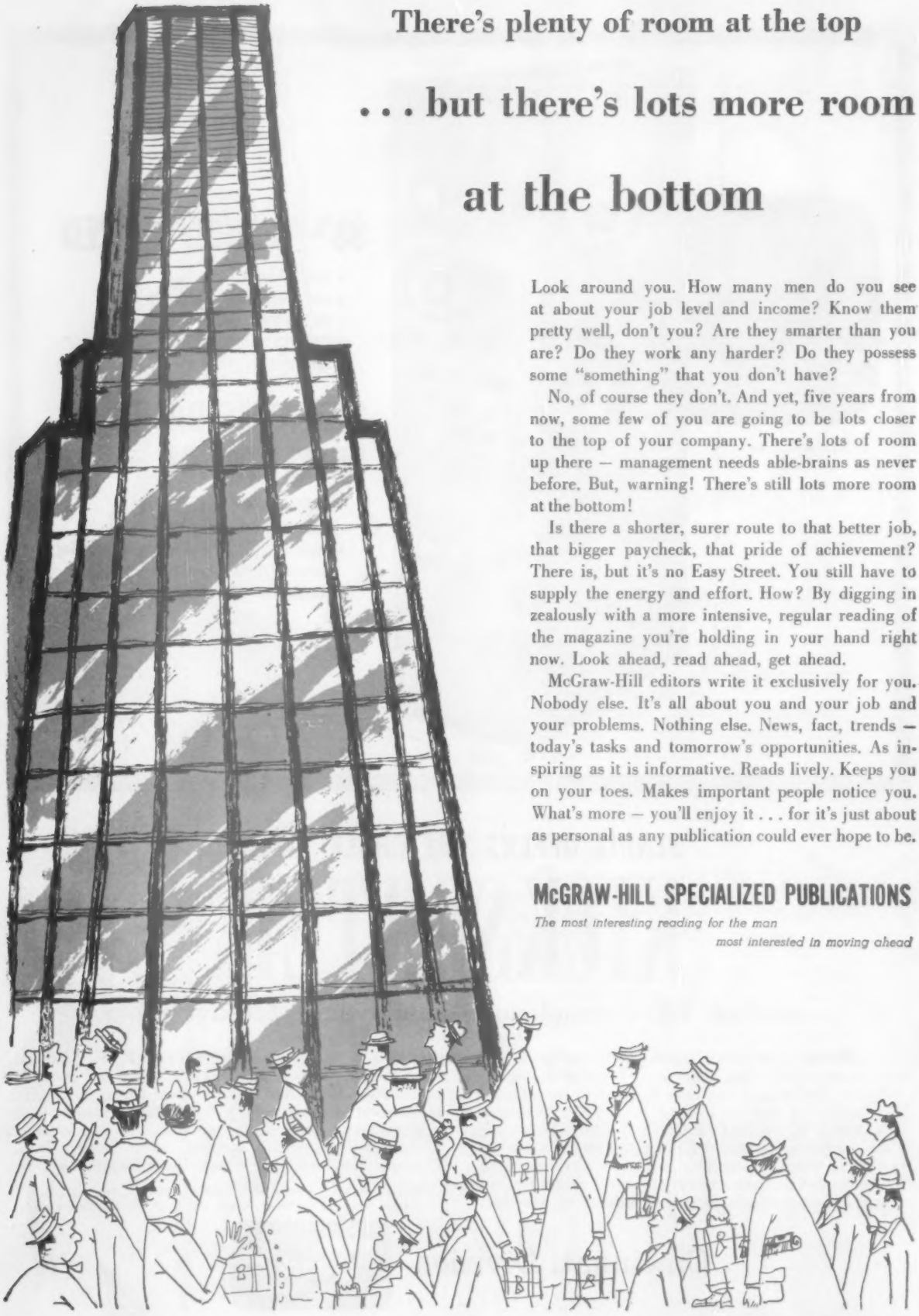
Export: Bendix International Division, 205 E. 42nd St., N. Y. 17, N. Y.
Canada: Computing Devices of Canada, Ltd., P. O. Box 508, Ottawa, Ont.

Cincinnati Division

Bendix AVIATION CORPORATION

There's plenty of room at the top

. . . but there's lots more room at the bottom



Look around you. How many men do you see at about your job level and income? Know them pretty well, don't you? Are they smarter than you are? Do they work any harder? Do they possess some "something" that you don't have?

No, of course they don't. And yet, five years from now, some few of you are going to be lots closer to the top of your company. There's lots of room up there — management needs able-brains as never before. But, warning! There's still lots more room at the bottom!

Is there a shorter, surer route to that better job, that bigger paycheck, that pride of achievement? There is, but it's no Easy Street. You still have to supply the energy and effort. How? By digging in zealously with a more intensive, regular reading of the magazine you're holding in your hand right now. Look ahead, read ahead, get ahead.

McGraw-Hill editors write it exclusively for you. Nobody else. It's all about you and your job and your problems. Nothing else. News, fact, trends — today's tasks and tomorrow's opportunities. As inspiring as it is informative. Reads lively. Keeps you on your toes. Makes important people notice you. What's more — you'll enjoy it . . . for it's just about as personal as any publication could ever hope to be.

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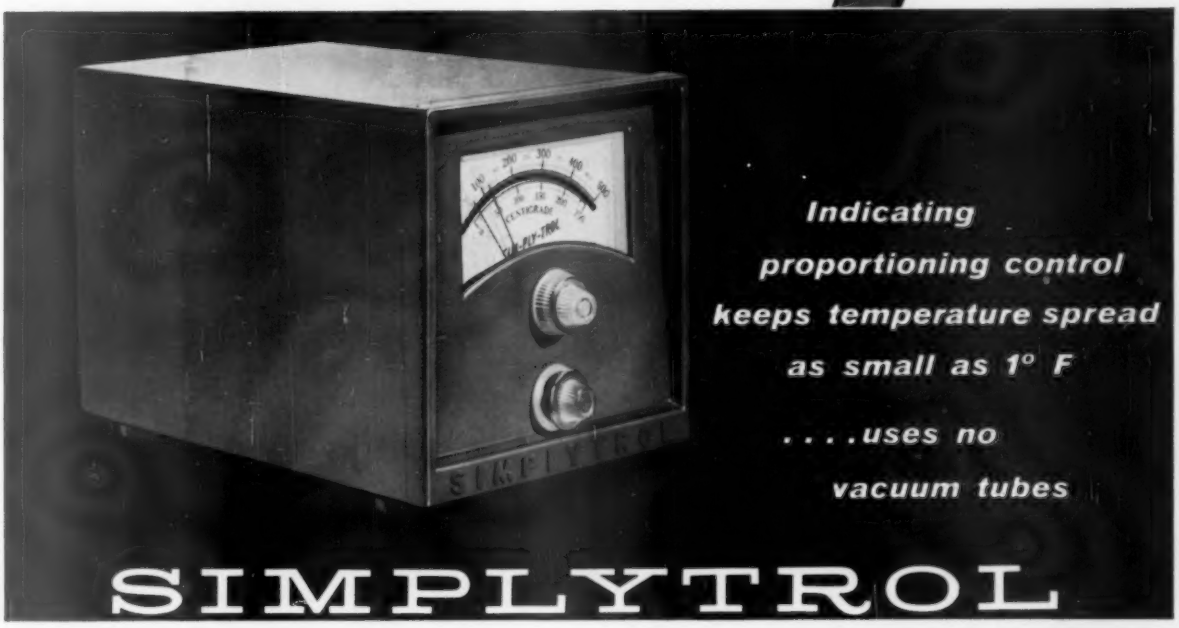
The most interesting reading for the man most interested in moving ahead

a new api meter-relay temperature controller that...



This Simplytrol time-proportioning control anticipates temperature overshoot, and shuts off heat in time to prevent it.

As the contact on the indicating pointer of the Simplytrol meter-relay moves close to the contact on the set pointer, an anticipating circuit permits electrostatic attraction between the contacts to build up.

The result is extreme sensitivity close to the set point, since any change in temperature there is greatly magnified. A very small rise shuts heat down; a slight decrease gives a longer duty (heat on) cycle.

Controls are thermocouple-actuated and give continuous indication without the distortion sometimes found in non-absolute systems. 21 ranges covering temperatures from –400° to +3000°F. List prices from $147 to $165.

Ask for Data Sheet No. 9.

Equally suitable for panel mounting or table use, the new Model 200 housing is 6½" x 6½" x 10" approx.

Assembly Products Inc.

75 Wilson Mills Road, Chesterland **28,** *Ohio • Phone (Cleveland) HAmilton 3-4436*

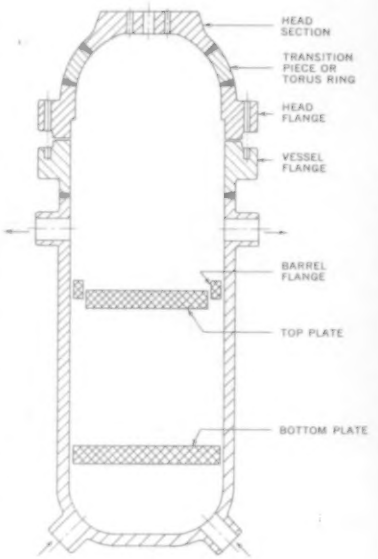
Specify api *meter relays with* LOCKING CONTACTS *for dependability*

Booth 1039, Design Engineering Show, Apr. 14–17, International Amphitheatre, Chicago

Critical-service reactor forgings "routine" at United States Steel

This closure-head forging for a nuclear reactor shell is a good example of how all United States Steel products are made to the tip-top edge of perfection. The reactor operates at very high pressure and is intensely radioactive. More than that, the entire shell, with its eight- to ten-inch-thick steel walls, is welded into a single, sealed unit. Can you imagine the prohibitive cost of replacing or repairing or even *examining* a forging that is in this type of service?

The small drawing shows a typical reactor vessel. "As-forged" diameters of the flange and transition forgings go up to 145 inches. They may be 30 to 50 inches thick, weighing up to 150,000 pounds in the rough. Head pieces, like the one in the big color picture, go up to 96 inches in diameter, 36 inches thick, 87,000 pounds.

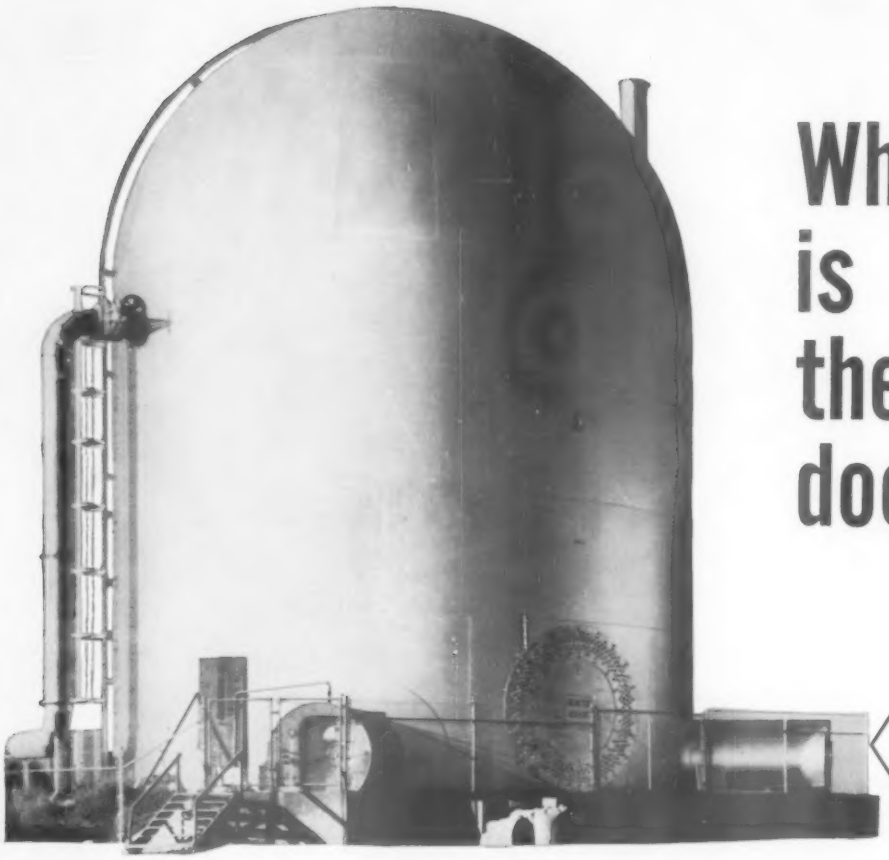


To make these mammoth forgings, we teem manganese-nickel-molybdenum killed steel ingots that may weigh a quarter-million pounds. The ingots are cogged, upset, punched and mandrel-forged (in the case of ring forgings) and are annealed, double normalized, and double tempered—a process that may take as long as 700 hours. Then comes the rough machining on vertical boring mills, and quench and temper heat treatment. Inspection procedures are elaborate: ultrasonic inspection, magnetic particle inspection, plus tangential tensile, Charpy V notch impact, grain size and bend tests.

It's no surprise that so many builders of nuclear equipment specify and depend on USS Quality Forgings. The men of our Homestead Forgings Division who produce these parts have had a great deal of experience turning out equally critical forgings, such as the perfectly balanced shafts for steam turbines and generators. Critical work like this is routine, and perfection is a habit for the men who make USS Quality Forgings.

You get this same quality in *any* forging you order, because the same crew of highly skilled men work on every order, using the same steelmaking facilities and the same shop equipment. If you specify a USS Quality Forging, you can be sure that money won't buy anything better. We'd appreciate your inquiries or requests for our free 32-page booklet on USS Quality Forgings. Write to United States Steel, Room 2801, 525 William Penn Place, Pittsburgh 30, Pa.

USS United States Steel



Where is the door?

These two tubular entrances are the Pratt Air Locks in the Vallecitos Boiling Water Reactor at the General Electric Vallecitos Atomic Laboratory at Pleasanton, California.

The Henry Pratt Personnel Air Lock

provides easy passage in and out of containment vessels in full compliance with the AEC code for reactor construction.

While the Air Locks are designed and built specifically for each atomic power plant, they all include some very desirable Pratt developments.

An interlocking feature that keeps one door shut while the other is open is typical of the many simple operating principles that add up to a high safety factor. Any arrangements of automatic and manual controls can be incorporated.

The locks can be built to withstand any practical pressure with compression or pneumatic door seals . . . size is no problem—locks are now being built that will accommodate trucks.

Air Locks already installed . . . Two locks in the Boiling Water Reactor of General Electric's Vallecitos Atomic Laboratory, Pleasanton, California . . . Two locks in the M.I.T. Research Reactor.

Air Locks now being built. . . Three locks for the C.N.R.N. Reactor, Ispra, Italy . . . One lock for the Enrico Fermi Atomic Power Plant of the Detroit Edison Co., Laguna Beach, Michigan . . . Two locks for the 30 MW Test Reactor at the General Electric Vallecitos Atomic Laboratory, Pleasanton, California.

Manufacturers of
Personnel Air Locks
Rubber Seat Butterfly Valves
Turbine-Condenser Expansion Joints
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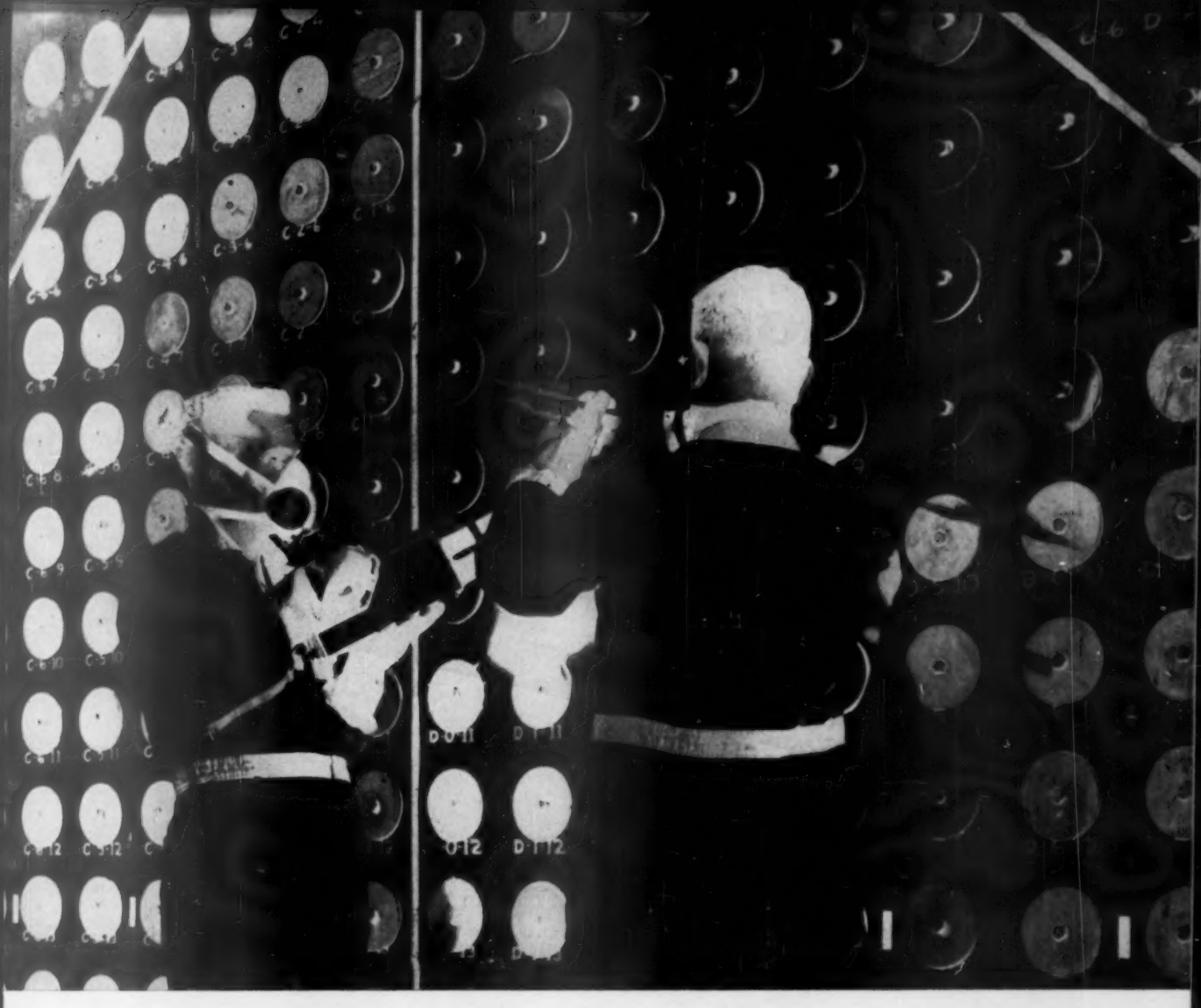
Specialized Steel Fabrication

HENRY PRATT

One of the two Pratt Air Locks now in use at the M.I.T. Research Reactor.

Henry Pratt Company, 2222 S. Halsted St., Chicago 8, Ill. Representatives in principal cities



Fuel-element irradiation studies at 1700°F

Irradiation studies of experimental fuel elements at high temperatures (1700°F) for a projected gas-cooled reactor design are now being carried out by Ford Instrument Co. engineers at the reactor facilities of Brookhaven National Laboratory.

Major aims of the fuel-element irradiation programs are to study fission product diffusion and leakage, and to secure radiation damage information. The studies are directed toward development of a fuel element that can be fabricated economically with a low reject rate, that uses material of low enrichment, that can be reprocessed economically and be economical of fuel inventory.

Irradiation of fuel elements at high temperature is just one of the nuclear studies and projects completed or now under way by Ford Instrument. Others include: design of a complete closed-cycle gas-cooled reactor, manufacture of control rod drive mechanisms (e.g., as used in the submarine, *Seawolf*), control rod position indicators, magnetic and transistor amplifiers for nuclear applications, and studies of control rod and reactor materials. In addition, Ford Instrument is conducting numerous feasibility and experimental studies in the nuclear field, including the application of digital techniques to reactor control.

To find out how you can put Ford Instrument nucleonic capabilities to work on your problems, write to Nuclear Sales, Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N.Y.

8.15

FORD INSTRUMENT CO.

DIVISION OF SPERRY RAND CORPORATION

A CREATIVE TEAM OF SCIENTIFIC, ENGINEERING AND PRODUCTION TALENT

NOW... A COMPLETE NUCLEAR "PACKAGE FUEL" PLAN

Another SYLCOR first! All the customer needs is the allocation for the nuclear material required in the fuel. For a single price, SYLCOR will do everything else, straight through to the delivery of the completed nuclear fuel elements.

SYLCOR's pioneering nuclear "package fuel" plan means substantial savings in both time and money to the users of nuclear fuels.

Here's how SYLCOR's plan works:

- SYLCOR will quote one fixed price which will be the *total and only* charge to the customer for the delivery of the completed elements for core loading.
- The customer need only obtain an allocation for the special nuclear material specifically required in the fuel. It will no longer be necessary for him to get extra allocation to cover scrap and losses in the production of standard enrichment fuels.
- SYLCOR will arrange and pay for the conversion of UF_6.
- Where rapid delivery is important, SYLCOR will supply from its inventory all special nuclear material required, replacing this material from the customer's allocation before delivery of fuel.
- SYLCOR will assume responsibility for processing losses and scrap reprocessing of special nuclear material.
- SYLCOR will pay all use charges during the entire fuel element production period, with the customer assuming the direct use charge on only the special nuclear material in his fuel element and only *after delivery* of the completed fuel elements.

The extreme simplification of this SYLCOR-developed "fuel package" plan permits SYLCOR to serve you better by providing the finest quality nuclear fuel quickly and economically. *For full details on this new complete nuclear fuel plan, write to our Marketing Staff at Sylvania-Corning Nuclear Corporation, Bayside, N. Y.*

SYLCOR

SYLVANIA–CORNING NUCLEAR CORP.

Interlocking lead brick and other unique lead protective products have been designed by Federated for the nuclear industry. Convenient lead containers, one pound to 10 ton casks, and larger to your precise specifications. Federated is long experienced in fabrication of cast, rolled and extruded lead products, sheet, plates, and piping. Asarco's Central Research Laboratory offers a wealth of information about temporary and permanent structures to house or transport radioactive materials. For lead protection call one of the convenient offices of Federated Metals Division of American Smelting and Refining Company, 120 Broadway, New York 5, N. Y. In Canada, Federated Metals Canada, Ltd., Toronto and Montreal.

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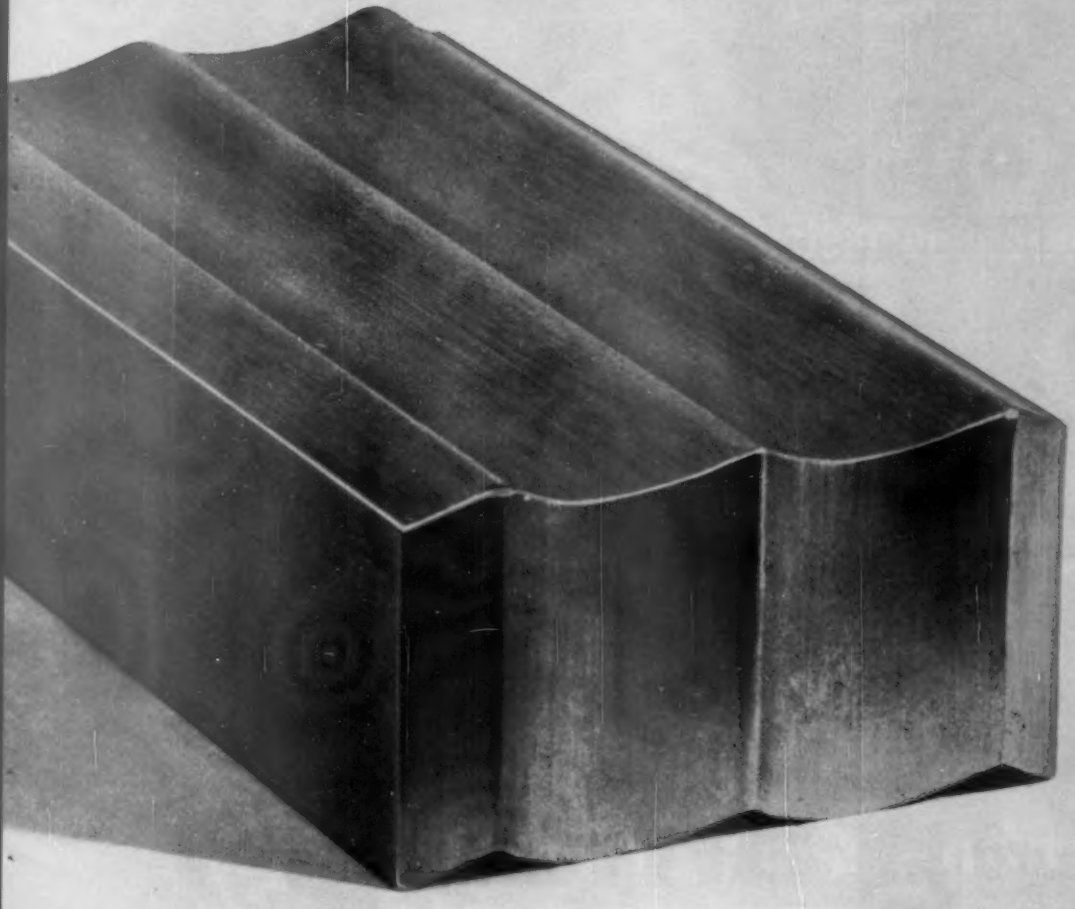

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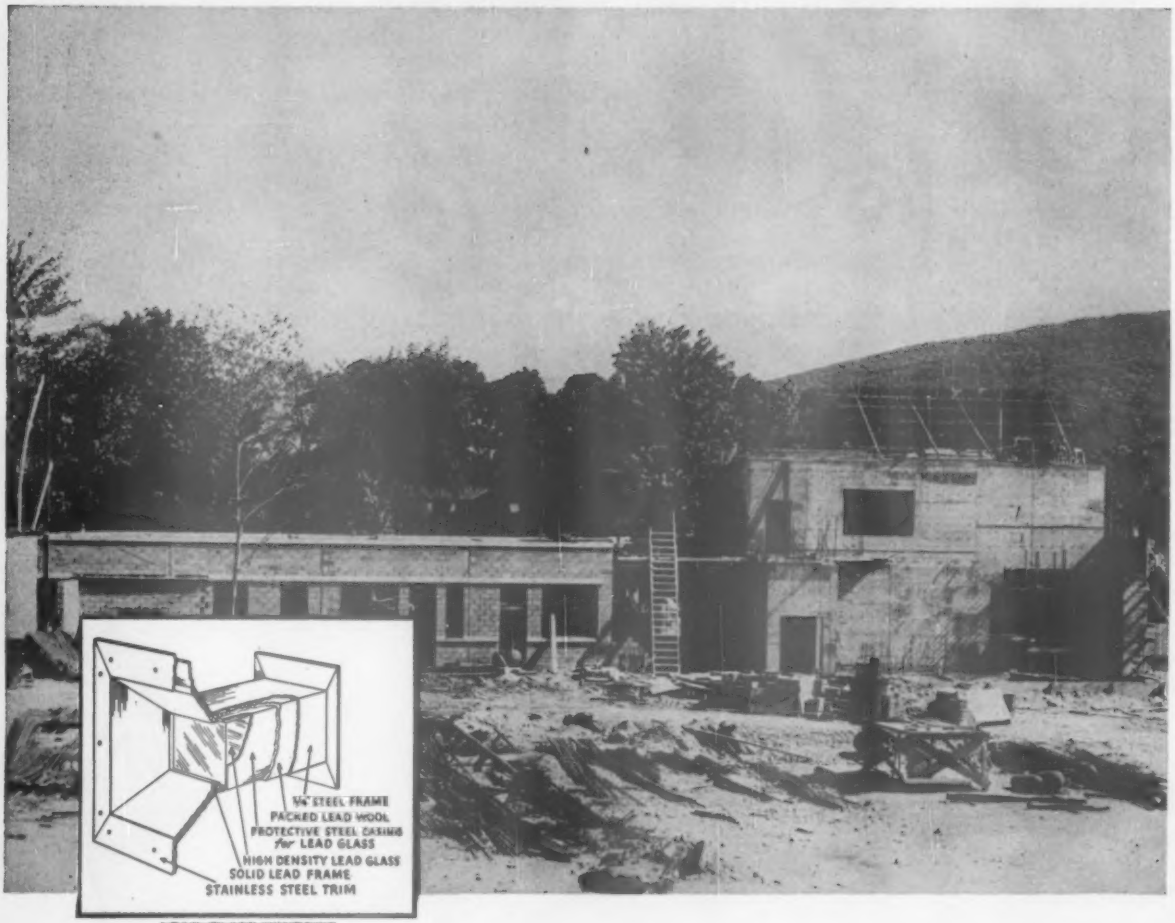
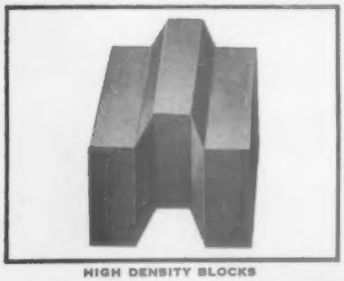


LEAD GLASS WINDOWS

SPENT FUEL ELEMENT CONTAINERS



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FOR ONE OF THE NATION'S MOST MODERN RADIATION LABS

This lab, upon completion, will set important inroads in handling and applying radioactive materials for industrial use. Ameray is furnishing and installing all shielding and allied equipment for this project.

These include shielded hoods and accessories; manipulators; electrically operated sample turntable; periscopes; electrically-operated, concrete-filled plug door; electrically operated monorail systems; access plugs and sleeves; isotope storage vaults; electrically operated, water-cooled isotope well; sleeves for pneumatic tube system; lead-lined doors and frames; and lead glass windows.

Whatever your own project requires . . . protective materials, devices or accessories . . . call Ameray's experienced engineers and scientists. They will work out conclusions for you that will be efficient and reasonable.

Write for Catalogs #37E and #57 which outline Ameray's capabilities in X-Ray and Nuclear protection

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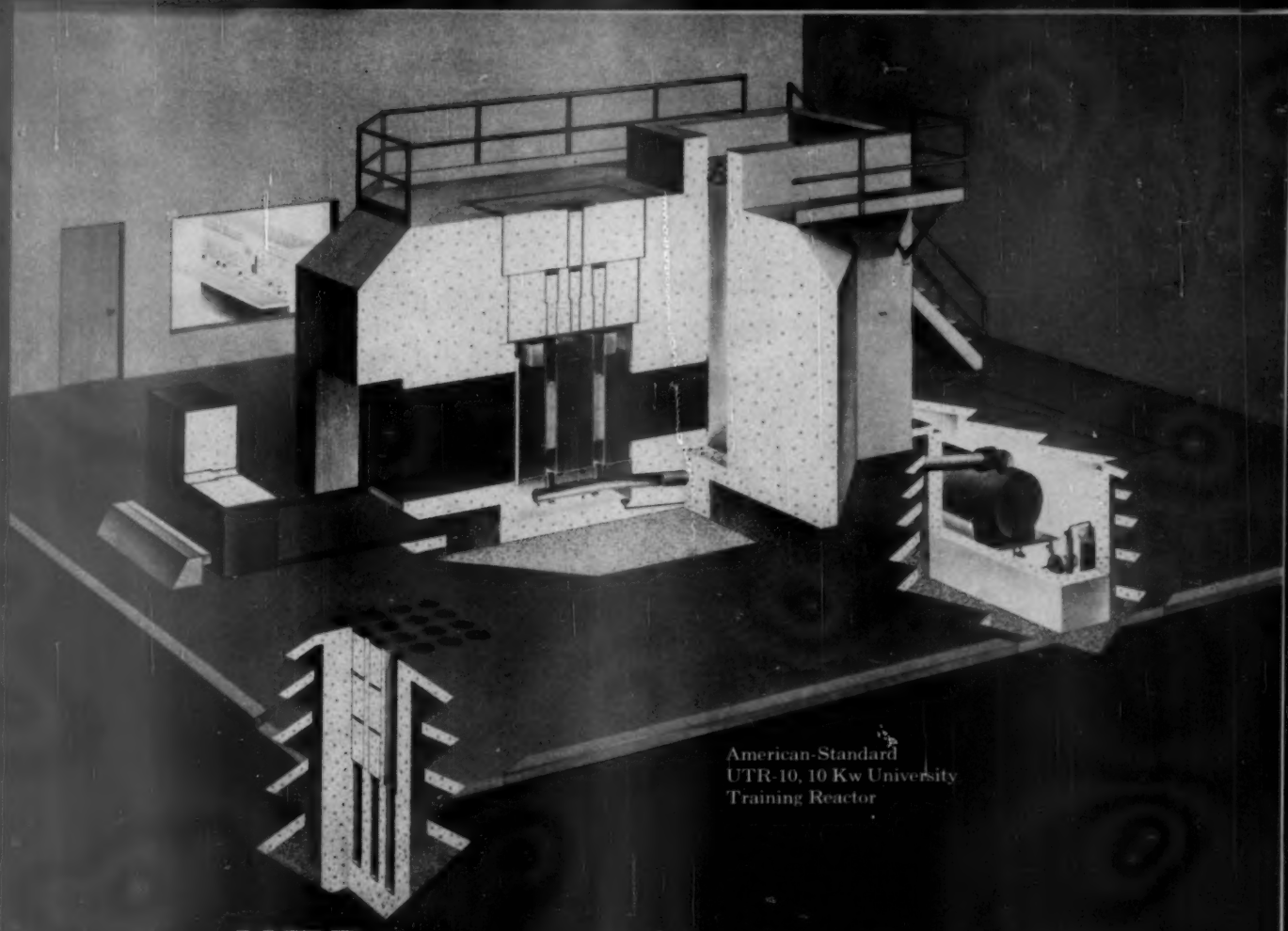

American-Standard
UTR-10, 10 Kw University
Training Reactor

UTR—High mark in nuclear education

The American-Standard UTR-10, an established training reactor design based on the Argonaut concept, will soon be undertaking classroom assignments in American colleges and universities.

As a training and research reactor, the UTR-10 has been completely engineered to provide the university with all the essential elements of a well-rounded nuclear engineering program – with safety, low cost and complete experimental facilities – ready to install in existing construction.

Write for your copy of the new technical bulletin describing the UTR-10 and its applications in detail.

New manufacturing facility of the American-Standard Atomic Energy Division, and site of the construction of a UTR-10 prototype.

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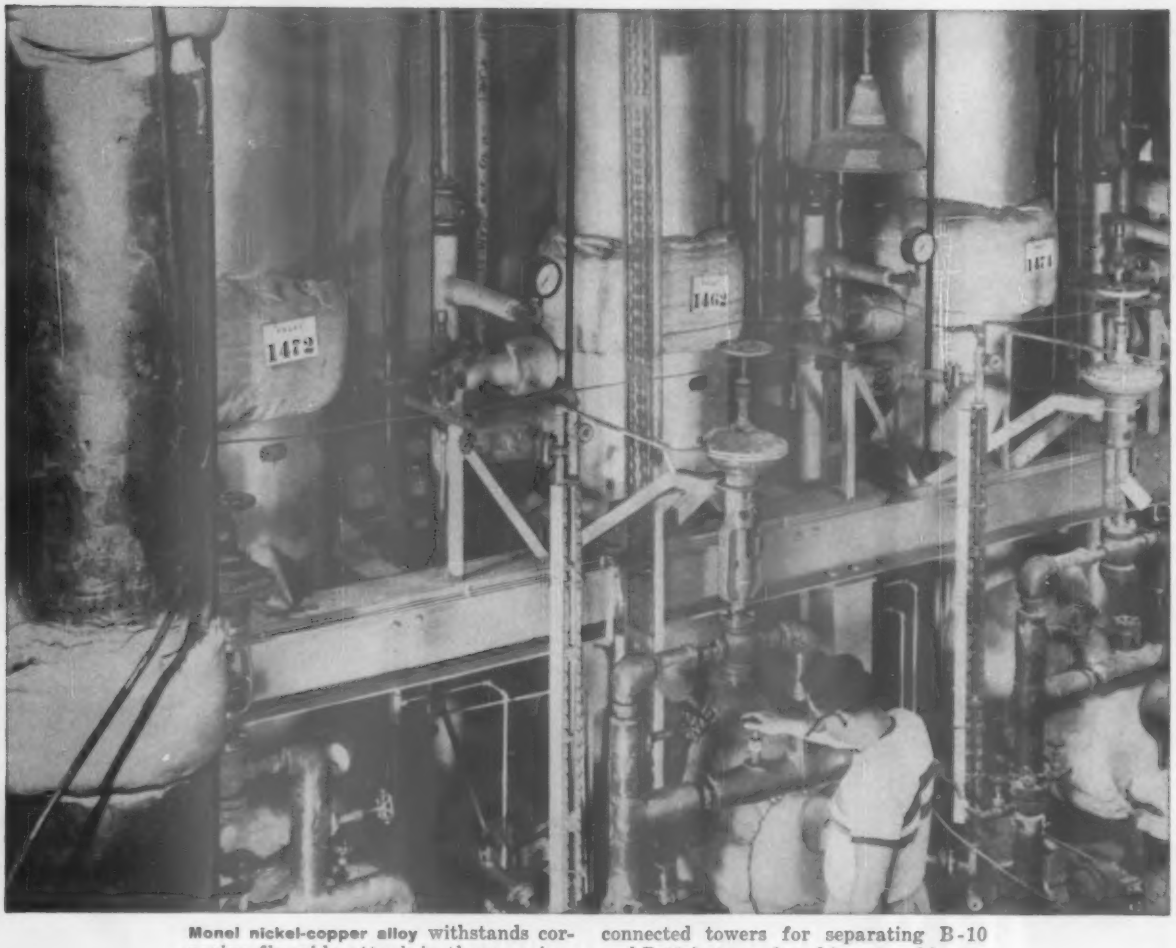

Monel nickel-copper alloy withstands corrosive fluoride attack in these series-connected towers for separating B-10 and B-11 isotopes found in natural boron.

Hooker "divorces" boron isotopes in unusual 350-foot, 6-tower, Monel fractionator

...gets 3 pounds per day of precious neutron-absorbing boron-10

The towers shown above are part of a six-tower fractionating system that may be the world's most effective. It is located in the AEC's Boron-10 plant, designed and constructed by Singmaster & Breyer and operated by Hooker Electrochemical Co.

In 350 feet of total height (they're connected in series) they enrich a dimethyl ether-boron trifluoride complex containing 18.8% B-10 to one containing 92% of this isotope.

Strangely, the separation of the B-10 and B-11 constituents does not depend on volatility. Instead it depends on a difference in the rates of association and dissociation of the DME-BF_3 complex. The lighter B-10 compound comes off in the liquid bottoms and the heavier B-11 compound in the vapor tops.

Corrosion potential is high

With fluorides at 105°C., and with the inevitable trace moisture present in a system of this type, a high corrosion potential is established.

For this reason, from the point where boron trifluoride enters the system via a Monel nickel-copper alloy reducing valve, most equipment is made of Monel* nickel-copper alloy ... tanks, columns, re-boilers, condensers, pumps, valves, piping.

Columns are filled with protruded Monel alloy packing

Monel alloy is highly resistant to the fluoride corrosion that is so often a problem in preparing isotopes and nuclear fuels. What's more, it has the high strength and fabricating properties needed for pressure vessels and allied equipment.

For technical assistance with your own corrosion problems, call on Inco's Development and Research Division.

*Registered trademark

The International Nickel Co., Inc.

67 Wall Street INCO New York 5, N. Y.

INCO NICKEL ALLOYS

NUCLEONICS APRIL, 1958

Jerome D. Luntz, *Editor*

Candor Before Geneva

ONE of the purposes of the second United Nations atomic energy conference, to be held in Geneva in September, is to bring East and West together on a friendly and cooperative basis. The first conference, in 1955, was eminently successful in this respect and showed that scientists the world over were not very different in their approaches to science, that they had a common bond. The experience then contributed in a small way to world amity. And so, presumably, will the 1958 conclave.

Much more could be accomplished in this regard by an even more intimate contact between the peoples of the U. S. and the U. S. S. R. This was emphasized by the new Soviet Ambassador to the U. S. recently when he said, "The more contacts between our two countries, the better off we both will be."

As in the Geneva conferences, atomic energy can be used very dramatically for this purpose to accomplish two ends at the same time—to improve relationships and to exchange information.

THUS, NUCLEONICS here proposes that Russia and the U. S. exchange small teams (perhaps five to ten men per team) of specialists in the field of power reactor technology. The Russian team would be taken on a tour of *all* U. S. civilian power reactor projects, government and non-government, and related facilities, and would be given the opportunity to have full discussions of these projects with the men in charge. The U. S. team would do the same in Russia.

The U. S. would be able to show the Russians the following operating reactors or reactors under construction and related facilities (with the cooperation of government and industry):

Experimental boiling water reactor and Argonne National Laboratory; Shippingport; homogeneous reactor experiment and Oak Ridge National Laboratory; sodium reactor experiment; organic moderated reactor experiment, materials and engineering testing reactors and National Reactor Testing Station; Vallecitos boiling water reactor; Dresden boiling reactor; PRDC fast breeder; Con Edison pressurized water reactor; Brookhaven National Laboratory.

We have many, many projects to show and to be proud of. Classification should be no problem. All the reactors listed are unclassified, and so, for the most part, are the national laboratories.

Opening these facilities to Soviet representatives would be substantial evidence of our desire to improve relationships. It is to this end that NUCLEONICS urges the State Department and the Atomic Energy Commission to take the initiative on making such a proposal to the U. S. S. R.

Here is a new opportunity for candor that can only be helpful.

If this proposal is implemented, it would be best to do it before the upcoming Geneva conference. In that way, the success of the conference would be fostered immeasurably.

Tubexperience in action

Made to pass the severest tubing test of all

14 different tests have proved it now ready for reactor use

*Superior tubing for applications in the atomic energy field is usually produced to meet highly exacting specifications. A length of tubing like the one shown above may well undergo all the tests and inspections listed here—plus special ones required by the customer.

1. Visual surface check
2. Dimension check (using precision measuring instruments)
3. Hydrostatic test
4. Eddy current inspection
5. Tensile and elongation test
6. Rockwell hardness test
7. Flare & flatten test
8. Dye penetrant (over entire length of tube)
9. Metallographic mount (for checking analysis, temper, grain size and structure)
10. Quantitative and qualitative analysis
11. Corrosion tests (Huey, salt spray, Strauss, autoclave, etc.)
12. Spectroscopic examination
13. X-ray inspection
14. Ultrasonic inspection

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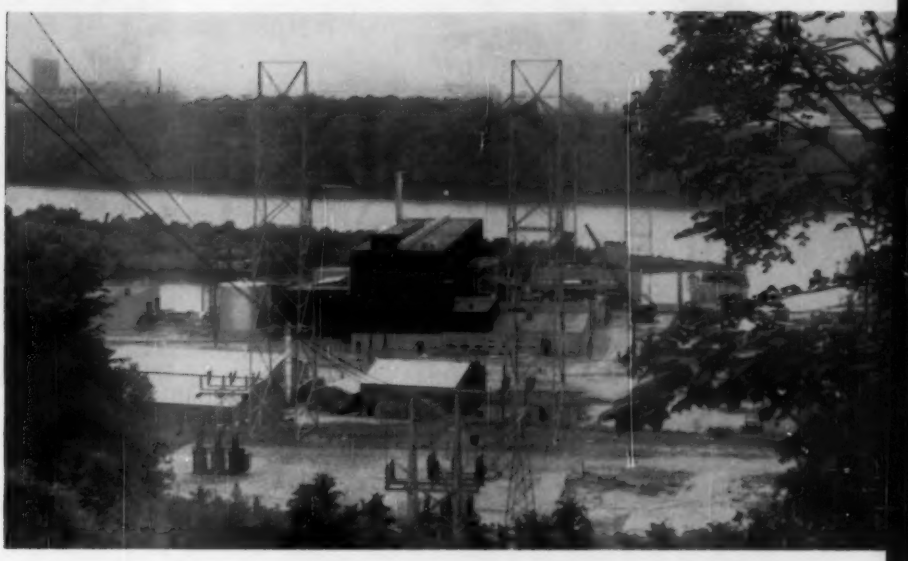
PWR



The Significance of Shippingport

Cradled in a bend of the majestic valley of the Ohio, in a natural amphitheater between the river bank and a protectively overhanging hill, is a shiny new central power station. For the Duquesne Light Company, the Westinghouse Electric Corp. and the Atomic Energy Commission, as for the entire atomic industry watching over their shoulders, completion of this plant represents the fruition of five years of intensive, pioneering effort.

For this is the Shippingport Atomic Power Station, which AEC proudly calls the world's first large-scale nuclear power plant designed and devoted entirely to generation of electricity for civilian use.

Shippingport was built to serve as a pacemaker for nuclear power engineering—to help solve the myriad problems of physics, materials, component design, corrosion, heat transfer; to yield operating data on serviceability, stability under load, maintenance, nuclear power plant safety; to show the way to cost reductions; to be the first of a family of large central-station pressurized water reactors. This is why Shippingport is important.

And this is why, in this special report, **Nucleonics** tells not only about what Shippingport is, but, more important, what Shippingport **means**—to reactor designers and to the electric utility industry, in the U. S. and throughout the world. We report here on a plant that is the result of eleven years of pressurized-water technology.

A NUCLEONICS Special Report ▶

PWR

FOR NUCLEONICS

Rickover Speaks of Shippingport

Hyman G. Rickover

" . . . primary objective . . . to gain information, advance reactor technology . . . "

Developmental nature of PWR. The things we have done on the PWR project have necessarily established precedents for nuclear power plants which will follow. We tried not to over-design; however, because the PWR is the first large power reactor and because we desire to obtain scientific data, we did some things which may not be necessary to future plants. I refer to such items as special test instrumentation of the reactor core and the use of criteria which give us flexibility in designing future cores. This is the important thing to realize about the PWR; it is not a modified aircraft carrier reactor. The PWR is the United States' first large-scale central station atomic power plant. Its primary objective is to gain information and advance reactor technology.

All PWR information unclassified. In order to insure that all of the technology developed in the PWR project is rapidly and widely disseminated, we have gone to considerable effort to put the entire project on an unclassified basis. On December 2, 1955, just two years to the day before initial criticality, an unclassified forum was held in Pittsburgh in which the technical status and plans of the PWR were presented in detail. Since then a great number of papers have been published, and all technical information concerning the design, development, construction and operation of the PWR is being reported on an unclassified basis.

Centralized control. I said at the December 1955 forum that I was applying to the direction of the PWR project the same type of centralized control and close coordination between the various organizations involved that was used on the *Nautilus* project. We have worked out a way for the Government, a development laboratory, and various manufacturers to work closely together on a difficult task in such a manner that development goals can be established at the beginning of the project and can be achieved in accordance with a very tight schedule. In 1953, before there was even a design for the plant or the reactor, a completion date of "the end of 1957" was set as the earliest possible date that the plant could be built assuming around-the-clock effort. In December 1957 the plant began delivering electricity to the city of Pittsburgh at its full power capacity of 60,000 kilowatts net electrical power.

Handling development problems. The success of the PWR design and development depended from the start upon the personal effort of many people in several organizations; John W. Simpson and his people at the Westinghouse Bettis Plant, Lawton D. Geiger and his group at the AEC's Pittsburgh Area Office, the personnel of the Duquesne Light Company, worked closely with me and my people of the Naval Reactors Branch. This close personal working relationship was the key to rapid solution of the many difficult and unusual problems which were encountered.

Let us take one example. We placed a great deal of effort on developing a metal fuel alloy, but by 1956 the information showed that metal fuel might not be completely satisfactory. Considerably less information was available on the alternate possibility, uranium oxide. I met with the technical people of Westinghouse and my own staff and all of the facts known to all of us were discussed. The decision to go to the oxide was then made by the Naval Reactors Branch and I took personal responsibility for the consequences. I believe that this type of operation, in which management is centralized, in which decisions can be made quickly, and where personal responsibility is taken by management for technical decisions, has been shown to be an effective way to carry on this difficult kind of parallel development and construction.

H. G. Rickover

Chief, Naval Reactors Branch
U. S. Atomic Energy Commission

PWR Meaning to Utilities

THERE ARE TODAY 123 of 424 privately-owned U. S. electric utility companies involved, to a greater or lesser degree, in building or studying nuclear power plants. These companies all have one eye fixed on Shippingport; none are watching it more closely than Con Edison of New York and the New England combine Yankee Atomic Electric Co.—the two utilities now following in the footsteps of AEC-Duquesne in building pressurized water plants.

One area in which they expect considerable help from experience at Shippingport is on estimating operating and maintenance costs.

"We have no fixed concept of what operating and maintenance costs, including labor, testing, and spare parts, may be for a nuclear plant, and so all our estimates come in on the high side," says a spokesman at Con Edison. "For example, we have no idea how many lab technicians, health physicists, plant chemists, etc., we'll need. There's a difference of opinion whether we should have our own health physicists at the plant: one school says we won't need one on each shift sitting around—that whatever may happen, we would have time to telephone the health physicist to come over.

"We have got to have operating years—not weeks, years—on large-scale plants before we know what actual costs are going to be, or before we even have a sound basis for estimating. At Indian Point we are allowing 0.09¢/kwh for operation and maintenance, as compared with 0.063¢ actual cost last year at a fairly new conventional station. So about 50% is padding for anticipated unknowns."

On the other hand, it is generally recognized that Shippingport will provide only guidelines rather than blueprints in this regard: the same difficulties arise here as with capital costs in trying to separate actual power plant costs from experimental facility costs.

Duquesne itself is looking at its newest plant with a speculative eye. Its picture of what Shippingport could mean to competitive power has come into sharp focus:

"One of the biggest things Shippingport can contribute to the art," says Duquesne vice-president Lyman, "would be a failure-proof fuel element. If you could ever demonstrate that you can economically build such an element, the whole design of a nuclear power plant would be changed; if we could have the same confidence in the fuel element not failing that we do on conventional components, the entire conception of what the plant looks like would be different."

A utility considering a nuclear plant must find the following operational characteristics met if the plant is to approach the function of a conventional central station: **1.** It must be possible to start the steam generator when needed without excessive delay; **2.** it must be possible to load the plant to full capacity as fast as the electrical system requires and have it absorb transient load changes of speed and magnitude as the system demands; **3.** it must be capable of surviving the emergency of having its output suddenly cut off and yet be quickly restarted if required; **4.** it must be capable of being shut down when its output is no longer needed.

Shippingport was designed to meet these characteristics. How well it does so will be carefully watched by the nation's utilities.

A Statement for NUCLEONICS by Duquesne Light Co.

Despite the enormous increase in labor, material, and tax costs in the past 30 years, the electric utility industry is delivering electricity today at an average price which is only about three-fourths of what it was in the mid-20's, while the average price of residential electricity has been cut in half in that period. Very few businesses can match this record.

But what does the future hold? On the one hand, we appear to be faced with a continuing rise in the general price level. On the other hand, the effectiveness of our industry's principal methods of offsetting rising prices has been declining in recent years. As a result, it is doubtful that we can continue to hold down the price of electricity unless we develop some new methods of controlling our costs. At the present time the only new development in the electric utility industry which offers a chance for large-scale cost control, at least over the long term, is atomic power.

Research and development must continue indefinitely in order to assure maximum long-term exploitation of the atom. However, the only way to come to grips with the problems of ultimate economic utilization of the atom in the generation of electricity is by building and operating full-scale plants like Shippingport. At Shippingport the problems can be seen in full dimension and their economic significance accurately assessed. By operating Shippingport as an integral part of the Duquesne Light Company system, the electric utility industry's incentive to keep down the cost of electricity, as well as its long experience in power generation, is brought to bear on the problems. Shippingport is also an effective vehicle for providing the industry with immediate assistance in design, training of operating personnel, and understanding of operating problems.

Phillip A. Fleger

Chairman of the Board
Duquesne Light Company

PWR Meaning to Reactor Builders

THE MERE EXISTENCE of Shippingport, as a successfully operating plant, provides a benchmark useful to the industry. It is generally agreed that economics information, vital as it is, is virtually impossible to evaluate realistically before actual operating experience is obtained. As the first full-scale nuclear power plant in public utility service, Shippingport is a laboratory for the entire nuclear power industry, particularly for workers in the field of water reactors. It is an exploration of one method of building and operating a large reactor plant and of providing adequate safeguards in connection with operation near a large city. It is a facility in which a variety of designs of light water moderated and cooled cores can be operated, and it's expected that such a program of testing a number of different core designs will provide data that will help determine fuel cost of the power produced from each core design.

Lessons Learned

Specific lessons already learned from the experience of building the plant, as cited by the men of Shippingport, include these:

- It is not really known what materials are best. There's a good possibility they could have used less special materials. For example, mild steel might well perhaps have been used in the boilers instead of stainless steel.
- There are too many welds in the stainless pipe.
- There is probably a surplus of safety and control devices. Operating the plant will permit coming very much closer in deducing "what is really, honest-to-God, required."
- The 16 main coolant valves in the four primary loops cost $200,000. This is one obvious large economy that could be realized if a safe plant could be designed without them.

Leaders of the Yankee project—one of the two large-scale pressurized water power plants now being built in the wake of Shippingport—say of PWR, "We are standing on their shoulders." They see it as significant that where PWR, as an experimental plant, had to be deliberately spread out to make the parts accessible, Yankee will be able to make advances in the direction of greater compactness, hence economy. The Yankee plant will have its primary in a single container above the ground, instead of in four separate vessels underground. Yankee's designers point out that the basic fuel element design for the New England plant is a direct development from the PWR blanket, and that the control rod for Yankee depends largely on information resulting from the alternate rod development carried out on PWR.

As further operation of Shippingport develops additional experience, the information available will be factored into the Yankee plant within the limits of schedule considerations.

At Con Edison, the designers of the Indian Point plant—the other big pressurized water station under construction—also say they have followed Shippingport experience closely. "Our instrumentation is affected to a large degree by the instrumentation, and the research on instrumentation, done at Shippingport," they aver. "The research on seed elements at Shippingport bore some similarity to our core, but our core is an original one and our big contribution. The flow data in the primary circuit, which was carried to fairly high levels at Shippingport, has been reflected in the Indian Point design."

A Statement for NUCLEONICS by Westinghouse Electric Corp.

Mark W. Cresap Jr.

The world's first full-scale atomic power plant exclusively for the generation of electricity at Shippingport, Pennsylvania, is a first step only toward the civilian use of atomic power. But it is a fitting monument to the initiative, vigor, and expectations that are elements of American character upon which much of American accomplishment is founded. Through the construction and operation of Shippingport and other large nuclear plants to follow, this nation will gain the experience essential to achieving the goal of economic atomic power.

The successful, full-power operation of Shippingport on December 23, 1957, is the result of a pioneering effort which began nine years ago for Westinghouse and thousands of suppliers and subcontractors. Its success was foretold in early 1953 when the first submarine prototype nuclear plant operated in Idaho.

The work in atomic power which has been done over the last decade has established a whole new industry.

In our fortunate nation, electricity has been abundant. Electric power is a universal servant: in industry, on the farm, in the home. It is the basic source of our productivity and our standard of living.

But we know that our existing energy sources some day will be insufficient to generate the electricity we must have in the future. Without some new source of energy that future must mean insufficient power, or power at exorbitant cost. The atom can provide this vitally needed new energy.

The success of Shippingport will mean great benefit for people everywhere. Other countries do not enjoy our reserves of conventional fuels. To them, atomic energy is an absolute necessity today. Shippingport and the other atomic power plants now being developed and built are important steps in filling that need.

Mark W. Cresap Jr.

President
Westinghouse Electric Corporation

Characteristics of PWR

Location:	Shippingport, Pennsylvania
Owner:	U. S. Atomic Energy Commission
Operator:	Duquesne Light Co.
Prime contractor:	Westinghouse Electric Corp.
Architect-engineer:	Stone & Webster
On line:	December 18, 1957
Output—heat:	231 Mw*
—electrical:	60 Mw*

Component Design Data

Pressure vessel

Height:	32½ ft
Inside diameter:	9 ft
Wall thickness:	8⅜ in.
Composition:	carbon steel
Cladding	
—material:	stainless steel (304)
—thickness:	0.25 in.
Design pressure:	2,500 psia
Test pressure:	3,750 psia

Core

Configuration:	cylinder
Size:	6.8 ft dia × 5.9 ft
Fuel load—U^{235}:	75 kg
—natural U:	14.16 tons
Seed composition	
—water:	52.6 vol%
—Zircaloy-2:	34.1 vol%
—uranium:	13.3 vol%
Blanket composition	
—water:	43.5 vol%
—uranium dioxide:	30.0 vol%
—Zircaloy-2:	26.5 vol%
Endurance—seed:	>3,000 fph
—blanket:	8,000 fph
Conversion ratio:	1.1

Control rods

Configuration:	cruciform
Number:	32
Total rod worth:	25.6% $\Delta k/k$
Absorber length:	71.5 in.
Absorber material:	hafnium
Weight:	55 lb
Withdrawal rate:	11 in./min
Scram time:	1.35 sec

Control-rod drives

Type:	collapsible rotor
Number:	32
Power requirement:	220 v, 3ϕ

Seed elements

Type:	plate
Number:	32
Enrichment:	~93%
Plates per element:	60
Meat dimensions:	71.75 × 2.05 × 0.039
Meat composition	
—uranium:	6.33 wt%
—Zircaloy:	93.67 wt%
Plate temp.—avg:	580° F
—max:	740° F

Blanket elements

Type:	pellet
Number:	113
Enrichment:	natural
Bundles per element:	7
Rods per bundle:	120
Pellets per rod:	26
Pellet composition:	UO_2
Pellet dimensions:	0.3575 × 0.3494 in.
Pellet temp.—avg:	1,000° F
—max:	3,800° F

Nuclear Design Data

Moderator

Type:	light water
Average neutron energy:	0.0471 ev
Prompt-neutron lifetime:	5.6×10^{-5} sec
Eff. delayed-neutron fraction:	0.0077
Over-all temp. coefficient:	-2×10^{-4}/° F

Control requirement

Burnup:	10% $\Delta k/k$
Equilibrium Xe:	3.1% $\Delta k/k$
Peak Xe:	2.9% $\Delta k/k$
Equilibrium Sm:	0.7% $\Delta k/k$
Temp. coefficient:	2.6% $\Delta k/k$
Total:	9.3% $\Delta k/k$

Heat Transfer Data

Coolant

Type:	light water
Volume—total:	70,800 liters
—in core:	2,918 liters
Flow:	59,000 gpm*
Temp.—inlet:	507.2° F*
—outlet:	538.8° F*
Operating pressure:	2,000 psia
Pressure drop:	40.5 psi*

Heat flux

Seed—average:	98,400 Btu/ft²/hr*
—maximum:	418,000 Btu/ft²/hr*
—burnout:	1,350,000 Btu/ft²/hr

* Based on normal operation with three of four loops in use, fourth held as spare.

NUCLEONICS REACTOR FILE . . . NO. 5

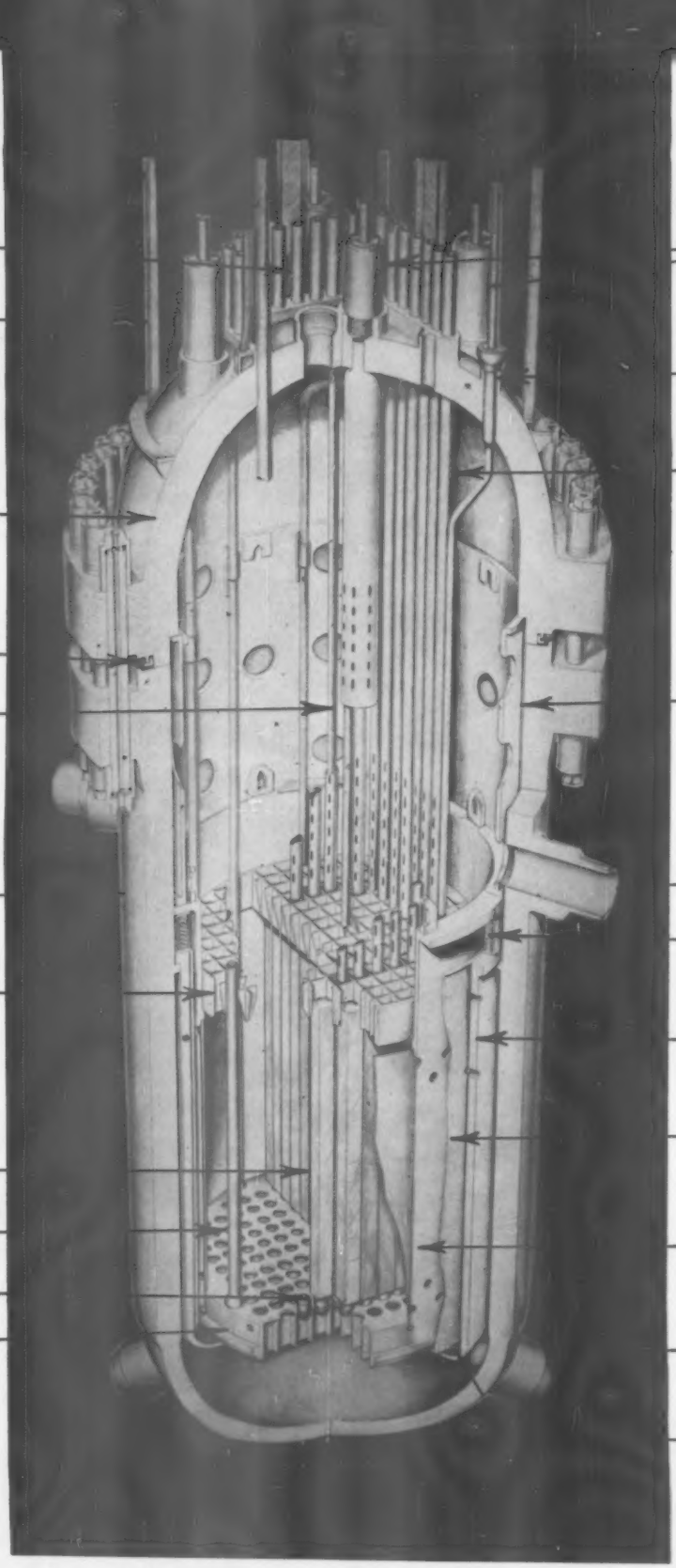
Reactors on the Line

PWR

Pressurized Water Reactor

This foldout is removable

tear along perforation



1 Cutaway view of PWR. Core-cage barrel is supported by helical springs and constrained by core-holddown barrel. Curved pipes above core are for instrumentation leads. Control-rod drive mechanisms are mounted on pressure vessel head and are protected by trellis structure (see Fig. 7)

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Refueling ports

Instrumentation port

Control rod shroud

Core hold down barrel

Outlet nozzle

Core support spring

Outer thermal shield

Inner thermal shield

Core support barrel

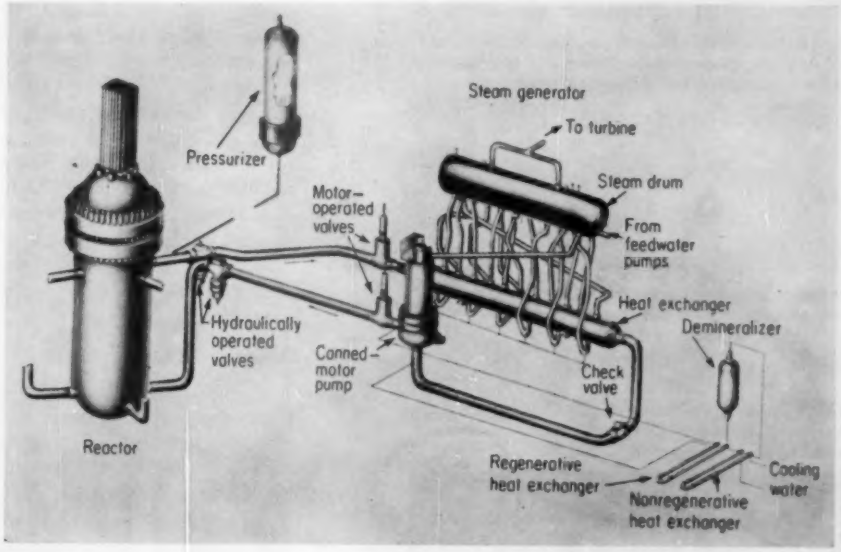
Inlet nozzle

Flow baffle

PWR on the Line

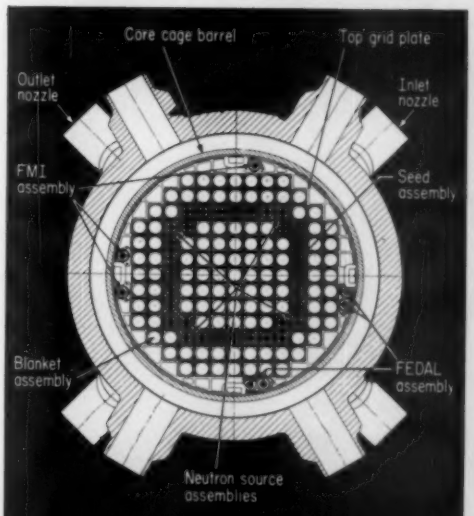
PWR went critical on December 2, 1957. The main generator was synchronized and the plant began furnishing electricity to the greater Pittsburgh area over the Duquesne Light Company's grid on December 18. PWR achieved its full-power design capability on December 23, three years and three months after ground breaking. As of the close of business on February 27, 10,578,800 kwh (net) of electricity had been generated.

During the five-year period that began December 18, Duquesne will purchase steam from the AEC at a rate of 8 mills/kwh of net electricity. Meanwhile, the last two phases of a five-phase testing program will be carried out. Importantly included in this program is the development and testing of advanced PWR cores. The first replacement core will probably be installed in 1961, with subsequent cores being installed at appropriate intervals.



2

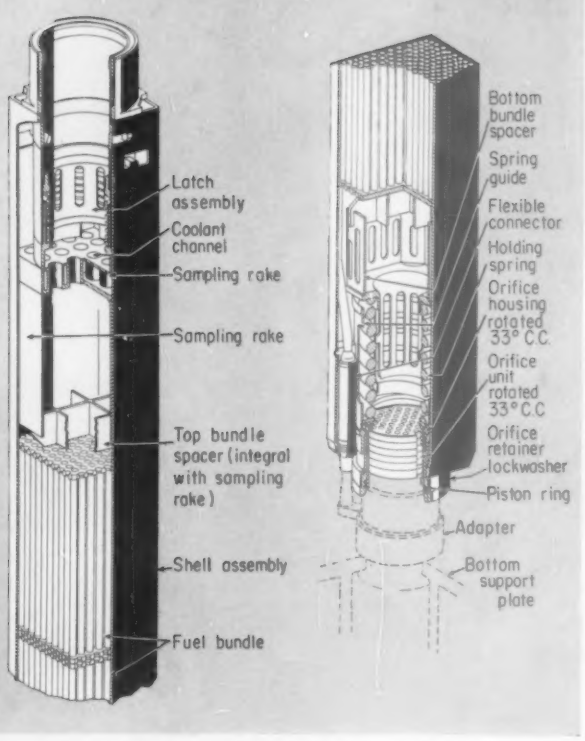
One loop of primary coolant system plus pressurizer. Of four loops, two have straight-through heat exchangers, two have U-tube type. During normal operation, only three loops are used; fourth is spare



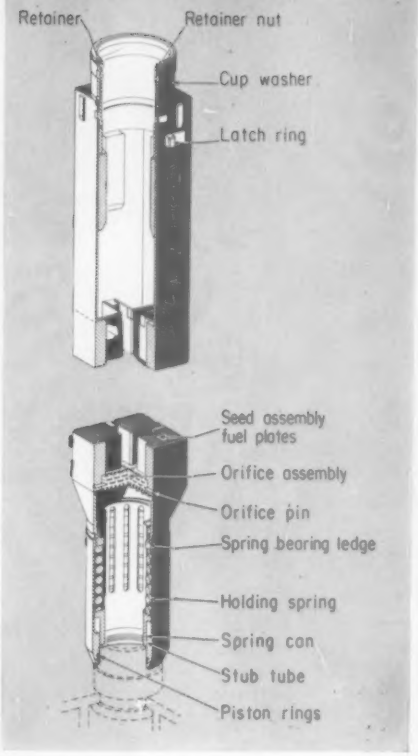
3

PWR core-loading pattern. 32 seed assemblies form hollow square; four contain neutron sources. 45 blanket assemblies are inside hollow square; 68 fill out 6-ft-dia cylinder

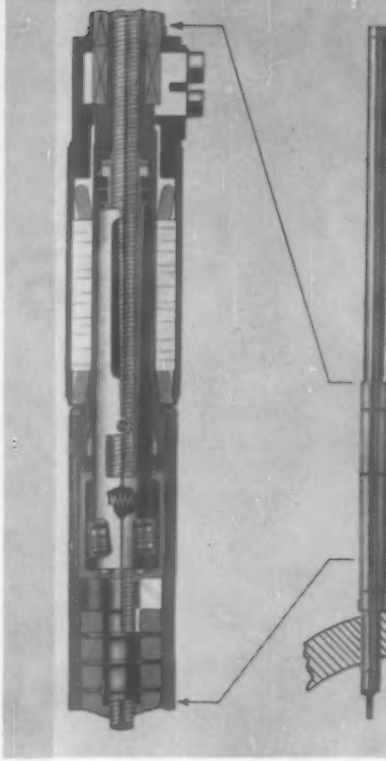
New York, N. Y.



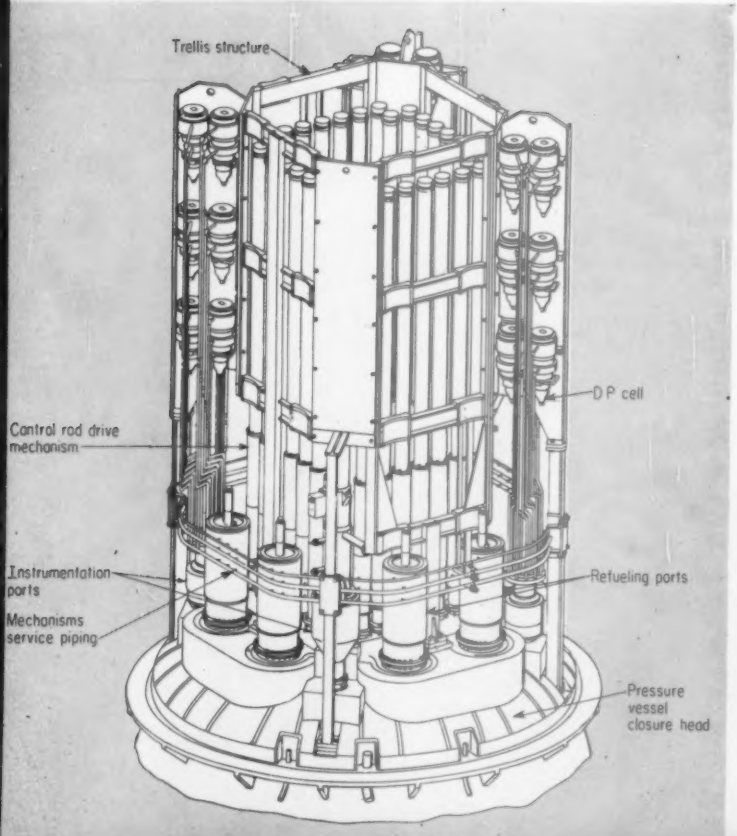
4 Blanket assembly includes seven fuel bundles, coolant sampling rake for failed-element detection and coolant flow orifices. Element is almost 9 ft long and 5½ in. square



5 Seed assembly is slightly longer than blanket assembly but has same cross section. Fuel plates form channel for cruciform-shaped control rods

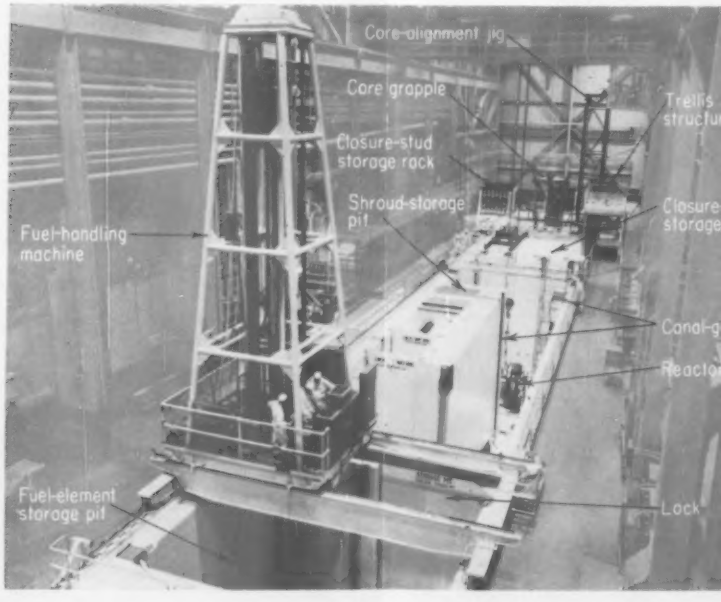


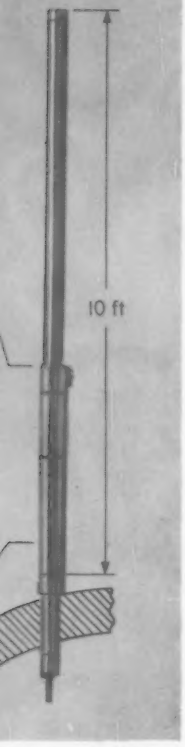
6 Control-rod drive mechanism has lead ing through rotor of motor. Rotor is with spring holding halves apart when rent flows



7 Trellis structure protects control-rod-drive mechanisms mounted on pressure-vessel head. Differential-pressure cells mounted on three corners of trellis are part of coolant-flow measurement system

8 Reactor building contains fuel-handling canal and equipment. Canal segmented so that some areas can be filled with water while others are dry. Partly equipped vessel head can be seen in reactor pit





as lead screw extend-
Rotor is split cylinder
rt when no stator cur-

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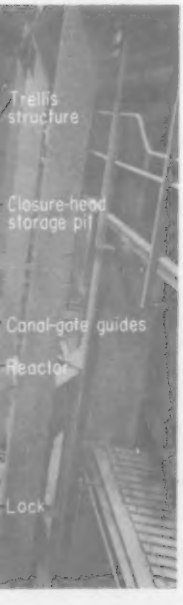
part of

t. Canal is compart-
others are drained.



Description of PWR

The Pressurized Water Reactor (PWR) is a light-water-cooled and -moderated thermal reactor with a seed-and-blanket core using a combination of natural and highly enriched uranium as the fuel.

Pressure Vessel

The pressure vessel (ASTM-A-302 Gr. B) is cylindrical with hemispherical heads. The vessel has a standard flanged and bolted top closure modified to use a gasket plus seal weld for final sealing. The vessel is formed of carbon-steel plates and forgings clad with stainless steel on the inside.

The hemispherical section of the closure head is formed of steel plate having a final thickness, excluding reinforcing bosses, of ~10 in. Reinforcing bosses compensate for the 46 penetrations through the closure head. Thirty-two of these penetrations are for control rods, 10 are refueling ports and four are for instrumentation access. The closure head is held to the vessel proper by forty-two 6-in.-diameter studs. The flanges have a 109-in. i.d. and 154-in. o.d.

The cylindrical portion of the vessel is fabricated in three courses, each course consisting of two semicircular plates welded together. The four inlet nozzles are located 90 deg apart in the bottom head. The four outlet nozzles are located 60 and 120 deg apart just below the vessel flanges. All of the nozzles are fabricated of 6-in. plate rolled and welded into a cylinder. The bottom head is 6.2 in. thick.

The pressure vessel is thermally insulated on the outside by 4 in. of glass wool that is packed to a density of ~4.5 lb/ft^3. The entire vessel fits into and is supported by the primary shield tank, the support point being just below the outlet nozzles.

Reactor Core Structure

A ledge around the inside of the pressure vessel supports two concentric thermal shields fabricated of type-304 stainless-steel plate. A dish-shaped stainless-steel coolant baffle is attached to the bottom of the outer shield. Resting on the top of the outer shield is a circular array of helical springs that support the core cage. The core cage consists of the bottom support plate and top grid plate separated and supported by the core-cage barrel. A core-hold down barrel is mounted between the core-cage-barrel flange and a ledge inside the closure head. The entire structure, except for some radial pin fasteners, is fabricated from type 304 stainless steel.

The core-cage barrel is a 1-in.-thick cylinder 13 ft high and about 8 ft in diameter. The bottom support plate is secured to the core-cage barrel at its lower end by radial pin fasteners of Haynes-25 material. Formed as a lattice of cells (each about 5¼ in. square on 6-in. centers), the bottom support plate is constructed of cross-shaped sections connected to a peripheral ring and covered by ¾-in. plates. Circular holes ~4 in. in diameter are machined through the cover plates to receive hollow cylindrical adapters. The adapters serve to support the fuel elements and to conduct the coolant from the plenum chamber below the bottom plate into the fuel elements. Venturi flow-nozzle contours are machined inside 36 adapters to provide differential pressure for flow measurement.

The top grid plate is positioned and fastened 27½ in. below the top of the core-cage barrel by radial pins. It is similar in construction to the bottom support plate except that there are no cover plates. The core-holddown barrel is a cylinder over 7 ft high and ~8 ft in diameter. The lower end is flanged and bears against a flange on the top end of the core-cage barrel. At the upper end, another flange is supported by gusset plates and bears against a shoulder on the inner surface of the closure head.

Control Rods

The control rod is a welded structure of cruciform shape with a lower (absorber) section of hafnium 71.5 in. long and an upper section of Zircaloy-2. The upper section terminates in a cylindrical boss that is threaded to receive a 17-4 PH stainless-steel adapter. A bayonet-type fitting, machined in the adapter, furnishes the means of remotely latching the control rod to the shaft of the drive mechanism. The span of the cruciform is 3⅜ in. wide, and the blades are 0.226 in. thick.

A shroud encloses each control rod and shaft from the top of the core to the vessel head. Bearings in the shroud control the alignment of the control rod with its channel in the seed assembly. Cooling is provided by allowing a small portion of the primary coolant from the seed assemblies to flow up into the shroud and out through slots.

Control-Rod Drives

Each control rod is moved by an electric motor that includes a combination rotor-nut and lead screw. The rotor-nut and lead screw are located inside a pressure tube in the mechanism housing attached to the pressure-vessel head. The stator and position-indicator coils are located outside the pressure tube. The cooling water in the tube is limited to 300° F by thermal barriers and external cooling coils.

The rotor-nut consists of two pivoted half cylinders, the nut portion of which is held away from the lead screw by springs when no current is flowing in the stator. Current to the motor is supplied by an inverter. When the inverter is not being rotated, a direct current flows through the motor and holds the control rod in a fixed position. The control rod is scrammed when the flow of current to the motor is interrupted. Under the action of springs, the rotor-nut disengages the lead screw and the control rod falls freely into the core. The velocity of the falling rod reaches a maximum of ~8 ft/sec and is reduced during the final 6 in. of travel to a maximum of 4 ft/sec by the action of a hydraulic damper.

Fuel Elements

Of the 145 fuel elements, 32 are seed assemblies arranged in a hollow square. The 113 blanket assemblies fill the square and completely surround it to form a cylindrical

# of PWR

he bottom plate into the fuel elements. Venturi flow-nozzle contours are machined inside 36 adapters to provide differential pressure for flow measurement.

The top grid plate is positioned and fastened 27½ in. below the top of the core-cage barrel by radial pins. It is similar in construction to the bottom support plate except that there are no cover plates. The core-holddown barrel is a cylinder over 7 ft high and ~8 ft in diameter. The lower end is flanged and bears against a flange on the top end of the core-cage barrel. At the upper end, another flange is supported by gusset plates and bears against a shoulder on the inner surface of the closure head.

Control Rods

The control rod is a welded structure of cruciform shape with a lower (absorber) section of hafnium 71.5 in. long and an upper section of Zircaloy-2. The upper section terminates in a cylindrical boss that is threaded to receive a 17-4 PH stainless-steel adapter. A bayonet-type fitting, machined in the adapter, furnishes the means of remotely latching the control rod to the shaft of the drive mechanism. The span of the cruciform is 3⅜ in. wide, and the blades are 0.226 in. thick.

A shroud encloses each control rod and shaft from the top of the core to the vessel head. Bearings in the shroud control the alignment of the control rod with its channel in the seed assembly. Cooling is provided by allowing a small portion of the primary coolant from the seed assemblies to flow up into the shroud and out through slots.

Control-Rod Drives

Each control rod is moved by an electric motor that includes a combination rotor-nut and lead screw. The rotor-nut and lead screw are located inside a pressure tube in the mechanism housing attached to the pressure-vessel head. The stator and position-indicator coils are located outside the pressure tube. The cooling water in the tube is limited to 300° F by thermal barriers and external cooling coils.

The rotor-nut consists of two pivoted half cylinders, the nut portion of which is held away from the lead screw by springs when no current is flowing in the stator. Current to the motor is supplied by an inverter. When the inverter is not being rotated, a direct current flows through the motor and holds the control rod in a fixed position. The control rod is scrammed when the flow of current to the motor is interrupted. Under the action of springs, the rotor-nut disengages the lead screw and the control rod falls freely into the core. The velocity of the falling rod reaches a maximum of ~8 ft/sec and is reduced during the final 6 in. of travel to a maximum of 4 ft/sec by the action of a hydraulic damper.

Fuel Elements

Of the 145 fuel elements, 32 are seed assemblies arranged in a hollow square. The 113 blanket assemblies fill the square and completely surround it to form a cylindrical core. The seed, containing highly enriched uranium, provides most of the reactivity with the blanket acting as a multiplying reflector. Based on gross dimensions, all seed assemblies are interchangeable with all blanket assemblies, and both are designed to be individually replaceable.

Seed assembly. The basic component of the seed assembly is the fuel plate, which is fabricated by sandwiching an enriched-fuel alloy strip between two Zircaloy-2 cover plates and four side strips. A subassembly is constructed by stacking 15 fuel plates and two end plates to create a pattern of alternate plates and coolant channels. The fuel section of the assembly is formed by joining four subassemblies and four Zircaloy-2 spacers such that a cruciform-shaped channel is provided for the control rod down the center of the assembly.

A Zircaloy-2 upper extension bracket and lower transition piece are joined to the ends of the fuel section. Joined to the lower transition piece is a 304 stainless-steel assembly containing an Inconel-X holding spring and Haynes-25 piston rings. The holding spring is assembled with a preload of 450 lb. The latched cold spring force of 1,050 lb decreases to 900 lb at operating temperature.

Six of the seed assemblies differ from the standard ones in that they contain thermocouples of the core instrumentation system. Four more differ in that they are designed to contain neutron sources.

Blanket assembly. The basic component of the blanket assembly is the fuel rod, which consists of 26 fuel pellets stacked inside a Zircaloy-2 tube 9½ in. long and having a 0.411-in. o.d. The pellets are right cylinders of sintered UO_2. A fuel bundle is formed by securing 120 fuel rods, arranged in a square lattice with 0.055-in. spacing, to two tube sheets, one at either end. Spaced holes through the tube sheets provide for coolant flow through the bundle. Seven fuel bundles are installed end-to-end in a square tube of Zircaloy-2, and the subassembly is capped on either end with an upper extension bracket and lower transition piece similar to that of the seed assembly.

Core Instrumentation

Included in the core are four instrumentation systems for information about (a) coolant temperature, (b) seed fuel-plate temperature, (c) failed-element detection and location (FEDAL) and (d) flow measurement (FMI). The coolant and seed fuel-plate temperatures are measured by 52 and 36 strategically placed thermocouples. The FEDAL system continuously samples coolant effluent from each of the 113 blanket assemblies and conducts it to two fission-product monitors. A multiport valve on the pressure-vessel head continuously switches to direct the effluent from successive pairs of assemblies to the monitors. Discharge from the monitors is returned to the primary coolant system. The differential pressure across the flow nozzles of the adapters in the bottom support plate under each of 36 seed and blanket assemblies is transmitted to DP cells mounted on the trellis above the pressure-vessel head to measure the flow through those assemblies.

PWR Engineering the Reactor Plant

IN ENGINEERING PWR the over-all guiding principles were plant safety and plant reliability—both as a power plant and as an experimental facility. Early in the design these principles together with the more specific criteria listed below the figure at the right led to the following set of design ground rules:

- Failure of any single component should not result in plant shutdown. (This prompted the installation of a fourth primary-coolant loop as a spare.)
- Reactor-plant equipment should be removable from service for repair while the plant continues to operate.
- All equipment handling hot pressurized coolant should be capable of being hermetically sealed.
- The plant should be capable of continuing operation even though as many as 1% of the fuel elements develop small holes releasing fission products into the coolant.
- All pipe lines from the reactor vessel should be capable of isolation to prevent loss of reactor coolant in the event of a rupture.
- No pipe containing reactor coolant at high temperature and pressure should be located outside the container.

In addition, the original criteria led to specific reactor design features. The four reactor coolant loops represent a balance between the economic advantage of using fewer loops and the more severe development problems in using larger components. Even so, the canned-motor pumps used in PWR are four times the size of the largest ones built previously. The average primary coolant temperature of 523° F is a compromise between the desire for a lower temperature to reduce core-heat-transfer surface and the desire for a higher temperature to reduce boiler-heat-exchanger-heat-transfer surface. The 2,000-psi operating pressure is about as low as one can go and still generate 600 psi steam without boiling in the reactor and without increasing boiler- and core-heat-transfer areas. To provide for advances in reactor technology, the secondary steam plant was built for a maximum gross output of 100,000 kw(e). Initial core design, however, assumes a net output of 60,000 kw(e) with three reactor coolant loops in operation.

Rod control was selected over chemical control for the reactor plant. Although chemical control is not clearly inferior to rod control for a highly enriched core, in a seed-blanket core chemical control significantly reduces the amount of power from the blanket. In addition chemical control does not appear as completely fail-safe as rod control. Rod programming for constant average coolant temperature (t_{av}) was adopted for simplicity in plant control. This automatically leads to a steam pressure varying with load, thus diverging from conventional-power-plant practice. The no-load steam pressure is 850 psia and the design steam pressure at full load is 600 psia.

The choice of stainless steel as the primary-system material was in large part based on the demands to be made on PWR as an experimental facility. Given sufficient development, less expensive materials such as low-carbon steel may very well prove suitable in future pressurized-water power plants.

Containment

The reactor-plant container was designed to accommodate the vapor that could be formed from release of all the primary coolant, plus the water and steam from the secondary side of one steam generator. It also was

Specs for PWR
(as set by AEC, July, 1953)

1. **Net generated output of at least 60,000 kw(e)**
2. **Saturated steam at 600 psia**
3. **Light-water coolant and moderator**
4. **Slightly enriched U fuel* with lifetime in excess of 3,000 Mwd/ton**
5. **Minimum shutdown period for refueling**
6. **Simplified reactor control system**
7. **Central-station-type turbine and electrical generating equipment**
8. **Commercial equipment to be used wherever practicable**
9. **Concrete shielding**
10. **Minimum construction costs**
11. **Minimum operating costs consistent with all other specifications**

*Changed to seed-and-blanket concept in December 1954 to reduce fuel costs.

decided that the container should be surrounded by a concrete radiation shield and be built substantially underground, because of short-lived N^{16} activity during operation as well as the radiation in the event of a fluid-system rupture. Study showed that the most economical undergound container would be a 50-ft-dia. cylinder of 1¼ in.-thick SA 201 grade B fire-box steel, with 600,000 ft³ gross volume (473,000 ft³ net volume after allowing for contained equipment and shielding), capable of withstanding an internal pressure of 52.8 psig.

FIG. 2. PWR canned-motor primary-coolant pump (one of four) is four times larger than Naval ancestors

The exact configuration of the interconnected multivessel plant container resulted from these basic requirements: (a) the reactor vessel had to be lower than the steam generators so that the core would be cooled by thermal circulation if a power failure stopped the pumps, (b) the boiler chambers were made as short as feasible to provide space for future power plants at this site, (c) the underwater refueling requirement meant that the reactor vessel had to be lower than the fuel canal, which was located at ground level for economic reasons principally.

The container was designed to have a leak rate of 0.1% in 24 hr. This leak rate was specified not on the basis that it was the maximum acceptable for safety but rather on a basis that it appeared impractical to measure lower leakages. Prior to installation of equipment, container leak tests were made using internal design pressures of 52.8 psi. These tests demonstrated the difficulty (primarily due to temperature changes during the test) of measuring a leak rate as low as 0.1%. After all equipment was installed in the plant, another leak test was run on the containers at 10 psi. During this test, temperature was eliminated as a variable by installing a network of copper tubing throughout the container in such a way that the average temperature of the tubing was approximately equal to the average temperature of the air. The leakage rate was then obtained by measuring the pressure difference between the leak-tight tube network and the container (NU, Aug. '57, 56). The method worked very successfully and indicated container is adequately pressure tight.

Pumps and Valves

The major mechanical components in PWR are similar to their counterparts in other pressurized-water plants —except, of course, that they are larger. For example, the PWR coolant-system-canned-motor pumps (see Fig. 2) each have an output of 18,300 gpm compared to 4,000 gpm for the largest pumps previously built for reactor service. The type-304 stainless-steel main coolant piping and valves are 18-in. o.d. in PWR compared to a maximum of 14 in. previously used.

In adapting the 3-phase, 60 cycle canned-motor pump design for PWR the 440-volt rating was discarded in favor of 2,300 volts because it would have hampered motor design as well as the design of cables, terminals and switchgear. Stator winding failures during tests of the production pumps were corrected by more rigid and frequent inspection and testing during the stator winding operation.

The main-coolant stop valves are hydraulically operated parallel-disk gate valves. During preinstallation tests, the pressure under the piston with the valve in the closed position was observed to spread the disks, thereby preventing valve operation. Since any further attempts to open the valve by increasing the valve-operating-system pressure also acted on the disks (which have seven times the surface area of the piston), the valve became locked in the closed position. The problem was resolved by piping the valve bonnet to a line leading to the reactor vessel. This line bypassed the valve disk adjacent to the reactor. Thus it is not possible to raise loop pressure above the reactor pressure unless a freeze plug is used in this bypass line. This is not considered a serious disadvantage since the valve still performs its normal function of retaining pressure in the reactor vessel when it is closed.

During initial plant testing, hydraulic surges from the routine operation of one valve were observed to cause spurious motion of other valves. This trouble was overcome by throttling valve-operating water flow and by changes in system operating procedure. The hydraulic valve-operating system was chosen in PWR over an electric or air-motor-operated system because of the difficulties of incorporating the latter two into a hermetically sealed system. However, significant savings in plant costs could be made by using such valves when they have been developed to the point of reliability.

Two approaches are open to future power-plant designers to reduce equipment costs. One involves modification of the plant design philosophy. The other is to reduce the number of components, either by combining two units into one (e.g., main-coolant pumps and check valves) or by eliminating components (e.g., main-coolant stop valves). The first approach involves things like dropping the extensive use of stainless steel and the requirement that the system be hermetically sealed. Either way, development work is required to prove that these things can be done safely and without markedly reducing reliability and increasing maintenance costs. The second approach is, however, more direct and will reduce costs more, over a shorter period of time. At present there is no major development program planned for PWR to reduce reactor-plant-equipment costs of non-core components.

Site Assembly Problems

In assembling the reactor at the site many unconventional problems had to

be solved. First the reactor system had to be assembled so that it would be as free as possible from dirt. This meant working out fairly elaborate procedures to ensure cleanliness, which slowed down the work considerably below normal rates on some phases of the project.

Another major problem was installing the core and its cage in the reactor vessel. The complete core cage with fuel weighs 115,000 lb and is a right circular cylinder 13 ft high and 9 ft in diameter (see Fig. 3). It had to be lowered without touching the sides of the reactor vessel lest galling occur. To do this core position had to be lined up within $\frac{1}{16}$ in. to insert the core into an alignment jig that then held the core position to within 0.015 in. during the lowering. Although the operation took about four hours, no troubles of any consequence developed during this time.

With the core in place and the head installed, any article dropped through an open fuel port would be practically impossible to retrieve so that extreme caution was required. Ironically, just before the last fuel port was sealed, a small gage block was dropped onto the top of the core but, fortunately, was retrieved by a strong magnet lowered through the port.

Some components built to fit with very close tolerances caused problems. For example, some of the threaded fittings in the primary system had to be reworked to looser tolerances before they could be assembled.

Water Chemistry

The chemical composition of the PWR coolant water is carefully controlled to assure that the materials in contact with it are not damaged, that heat-transfer surfaces are not seriously fouled and that buildup of radioactivity on reactor-coolant-system walls is minimized. The reactor-coolant-water chemistry conditions are maintained within these limits:

$$9.5 < \text{pH} < 10.5$$
$$O_2 < 0.14 \text{ ppm}$$
$$Cl < 0.1 \text{ ppm}$$
$$25 < H_2 < 50 \text{ cm}^3\text{/liter}$$

The pH of the reactor coolant is maintained with LiOH. High pH is used because it makes the corrosion film on the stainless-steel surfaces thicker and thus reduces the quantity of loose solid corrosion products in the system. One problem posed by the high pH was the possibility of caustic stress-corrosion cracking in stressed parts located where concentrations of caustic substances occur. A survey of the possibility of such concentrations gave negative results. Another problem of concern is the possibility of chloride-stress corrosion.

The oxygen content of the coolant is maintained as low as practical to reduce various forms of corrosion. Depending on the relative concentrations of the reactants, water can dissociate into hydrogen and oxygen, or these can combine to form water. If the oxygen present in the water was introduced as air, nitrogen present in the air can form either ammonia or nitric acid, or the two can be converted to one another, depending on whether free hydrogen alone or free oxygen is present simultaneously with nitrogen. These reactions can be summarized as follows:

Water dissociation and formation

$$2H_2O \rightleftarrows 2H_2 + O_2$$

Formation of ammonia

$$3H_2 + N_2 \rightleftarrows 2NH_3$$

Formation of nitric acid

$$2N_2 + 5O_2 + 2H_2O \rightarrow 4NHO_3$$

Reduction of nitric acid

$$2HNO_3 + 5H_2 \rightarrow N_2 + 6H_2O$$

The dissociation and formation of water proceeds at a rapid rate with the reactor operating. The other three reactions shown proceed at a slower rate. Thus, if an excess of hydrogen is maintained in the coolant, oxygen trapped in the system or otherwise added can be rapidly converted to water. In addition to this, during low-temperature start-up, oxygen is removed from the water chemically with hydrazine at about 200° F. Maintaining the hydrogen level at 25–50 cm³/liter gives a very low oxygen level. Because deaerated make-up water is used, the only significant nitrogen in the plant is that trapped at filling.

The design requirement that PWR be capable of operating with significant quantities of fission products in the reactor-coolant water inspired a number of questions. To get the answers sample PWR fuel elements containing holes drilled through the clad were inserted in in-pile pressurized-water test loops. These experiments developed information on the amount and type of fission products that escaped from a defective fuel element, how these fission products would affect activity buildup on the reactor-coolant-system walls, what methods were required for control of these fission products, etc. The work showed that system degasification would not be necessary for control of gaseous fission products, because of the short half-lives of the gases. They demonstrated that the normal PWR purification flow of 80 gpm through ion exchangers would control the long-lived soluble fission products. They also indicated primary coolant could be adequately decontaminated for discharge by the waste-disposal plant decay and then demineralization. In addition, satisfactory progress is being made on a development effort to select chemicals and procedures for decontaminating the internals of the reactor plant without damaging any of the equipment.

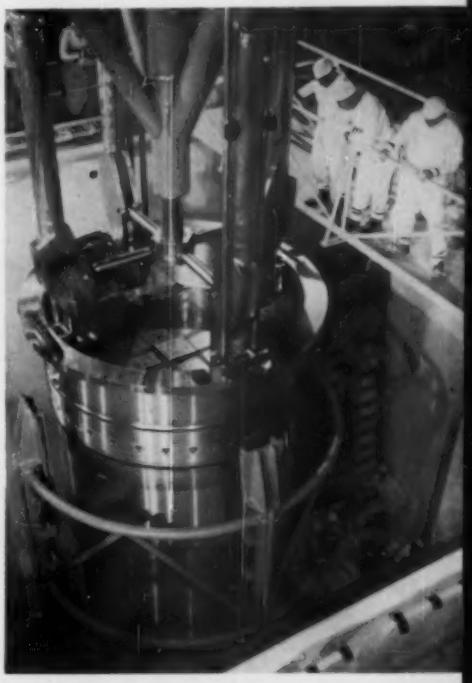


FIG. 3. Fully loaded core (except for four seed assemblies) is carefully lowered into PWR vessel

PWR

Shippingport Power Costs—What Do They Mean?

Detailed Breakdown of

The table gives inferred power costs such as a private firm would incur in producing electricity at Shippingport. Not taken into account is the out-of-pocket expense to the government for experimental operations.

The estimates assume a net electrical-power output of 60,000 kw produced by running at 100% load 80% of the time. The core life requires two seeds, the first lasting the equivalent of 3,000 full power hours; the second 5,000 full power hours, for a total of 8,000 full power hours—the blanket lifetime. Power production of the core is 50% from the seed and 50% from the blanket.

The use charge applies to the time of fabrication, use and reprocessing. It is assumed that manufacturing requires 1 year, reprocessing 6 months, blanket use 1 year and average seed use 6 months.

The fabrication and nonfissionable materials cost is derived from actual experience on the blanket and seed 1 and from an estimate for seed 2. This cost was incurred in Government-owned facilities with no charge for their use. These fabrication facilities were amortized at an average industrial rate of 14% per year.

Money in various amounts is required during fabrication, use and reprocessing and is included as an inventory carrying charge equivalent to 10% of the total core cost, including fissionable material.

No definitive figures on the cost of reprocessing depleted cores are available so it was taken as 20% of the value of the material to be salvaged.

The total amount for research and development spent on PWR to December 1957 was $48,900,000. $8,500,000 of this total is ascribed to plant engineering and is listed as part of the plant capital cost. The remaining $40,400,000 was spent on basic research considered applicable to all pressurized water reactors and therefore is not included here.

SOME NORMAL REACTIONS to PWR's impressively high power costs detailed above are: "Why are they so high?" and "What is the reactor good for if it's that expensive to run?" The answer to the first question is that PWR is expensive because it was designed mostly to produce information rather than power—and the reactor had to be built in a hurry. As to the second, the AEC feels that this information is important enough to underwrite the major part of the expenses of building and operating PWR. Except, possibly, for long-range fuel costs, PWR will never itself become a direct source of realistic cost data for nuclear power stations. But the PWR experience and data, as it is accumulated, should provide a basis from which cost data for nonexperimental power plants can be extrapolated.

The PWR capital investment charge, which accounts for about one-third of the power costs, covers the expense of extra design features convenient for test purposes but not at all necessary or desirable for a utility plant. Thus, instead of the four parallel steam-generating circuits, which allow PWR to keep running after a failure, a plant built to pay its way would have fewer such circuits and would shut down on failure. Likewise the arrangement permitting individual fuel elements to be replaced without removing the pressure-vessel head adds considerably to the cost and is not a necessity for a power reactor. The number of temperature, pressure and radiation-measurement points in PWR, while large enough to satisfy a reactor engineer collecting basic data, is beyond the needs of a power-plant engineer supervising plant load.

The need for haste also directly increased the size of the construction bill. The guiding philosophy was to use the quickest, surest method rather than take a chance or waste time on working out cheaper ways. To avoid lost time from blind alleys, parallel approaches were often used. For instance, in the search for a suitable fuel material both metallic- and ceramic-type fuels were studied. Although considerable money was spent in investigating metallic fuels, these were ultimately discarded in favor of uranium dioxide—the fuel type now being used or proposed for practically all heterogeneous type reactors.

Similarly, during the manufacture of

Shippingport Power Costs Shows 64.4 mills/kwh Net

CONSTRUCTION COSTS (thousands of dollars)	
Reactor	
Core	11,900
Reactor vessel	2,100
Reactivity control; core handling	3,000
Reactor coolant system	3,900
Auxiliary systems	5,800
Instrumentation; control systems	1,900
Special test equipment, spares, manuals	500
Installation	13,200
	42,300
Structures and facilities	
Plant container	2,400
Secondary shield; fuel-canal concrete	4,900
Fuel-handling; service buildings	1,900
Internal shielding; container drainage	800
	10,000
Architect-engineer	1,800
Expanded hot-lab facilities	500
Contingency	400
Subtotal nuclear portion	55,000
Estimated turbogenerator plant	17,500
Total construction cost	72,500
Noninvestment items*	−13,000
Plant capital investment	59,500
Nuclear plant design and engineering	8,500
Total capital investment	68,000
Annual fixed charge (14% of $68,000,000)	9,520
Capital cost per kwh	**22.7 mills/kwh**

* Includes the following expendable or research items: cost of core, $11,900,000; special test equipment, $200,000; hot-lab facilities, $500,000; contingency, $400,000.

FUEL, OPERATING COSTS (thousands of dollars)	
Fissionable materials	
Blanket (14.6 tons natural UO_2 @ $40.50/kg)	537
Seeds (182 kg highly enriched U @ $16/gm)	2,912
Seed processing loss	364
AEC use charge (4%/yr)	316
Fabrication and nonfissionable materials cost	14,200
Use of facilities (14% of $4,400,000)	616
Fuel inventory carrying charge (10% of above)	1,895
Total fuel cost	20,845
Fuel cost per kwh	**43.4 mills/kwh**
Fuel credits	
Blanket (13,280 kg 0.43%-enriched UO_2 @ $12/kg)	160
Seed (131.5 kg U^{235} @ $16,000/kg)	2,100
Plutonium (61.6 kg Pu @ $12,000/kg*)	740
Total	3,000
Less processing	−600
Net credit	2,400
Fuel credit per kwh	**5.0 mills/kwh**
Operating cost	
Salaries (130 men @ $5,400/yr plus 50% overhead)	1,050
Materials	350
Total	1,400
Operating cost per kwh	**3.3 mills/kwh**
Fuel and operating costs	**41.7 mills/kwh**
TOTAL POWER COST	**64.4 mills/kwh**

* Credit is taken for all Pu produced since it is assumed U^{235} burnup produced all the reactor heat.

the core a problem arose in connection with the weld integrity of the fuel-rod end caps. All manufacturing was stopped for a month until the problem was solved. The people who had been doing this work had to stay on the payroll and, although a part of them could be diverted to other work, most of them were charged to the project.

PWR's construction-cost experience will thus have only indirect meaning for future estimates of new plants. One can expect to learn what frills can safely be left out and what economic shortcuts appear feasible. But in making direct use of the PWR figures, each builder will have to judge for himself how much of the total price can be charged to that part of PWR that makes the power. This process will be aided, however, by the detailed records* kept by PWR engineers on reasoning behind design decisions in the first PWR core.

The nuclear-fuel cost is 15 times the cost of conventional fuel and accounts for about two-thirds of PWR's total power cost. Although this first figure is way out of range, PWR's fuel cost should in the long run be direct evidence of the ultimate capability of pressurized-water reactors in this area. While the reactor plant itself has been designed and built once and for all, each new core offers an opportunity to improve on the design and economic record of the last one. In fact, the AEC sees PWR primarily as a facility to gather data on core performance.

* Available as "system descriptions" through U. S. AEC Technical Information Service Extension, Oak Ridge, Tenn.

The observation that for the first core the cost of Zr-material fabrication accounts for over 40% of the total fuel cost (NU, Jan. '58, 96) while the cost of uranium for the core accounts for only 15%, points up at least one direction for improvement. In addition to developing less costly fabrication procedures, the charge for Zr per kwh can be brought down by extending fuel burnup. The present limit of 8,000 full-power hours for the blanket elements is equivalent to about 3,000 Mwd/ton. Indications are that from a reactivity point of view the blanket elements could be irradiated to a much higher burnup. The life-time of the seed elements is already being increased from 5,000 full-power hours (for the second seed in the first core) to 10,000 hours in the second core.

PWR

First Core In . . .

FIG. 1. 57.5 tons and $11.9 million—is suspended above reactor before insertion

Reactor Core Design

THE ECONOMIC FUTURE of pressurized-water reactors rests heavily on reactor-core performance. Thus one of the main reasons for building PWR was to use it as a core-test facility to get a better idea of how much performance can ultimately be squeezed out of a pressurized-water core. How well the PWR cores do—how high in power they can be pushed and how much burnup they can take—are things that will be watched closely by the entire nuclear world.

The design considerations behind Core 1 are presented here as a baseline for evaluating future trends. Core 1 already shows promise of exceeding its original lifetime-performance specs by a healthy margin; Core 2 (see top of facing page) will be even better.

Core Physics

The use of a seed-and-blanket-type core in PWR aims at the following objectives:

- A substantial amount of power produced in natural uranium
- A minimum investment of fully enriched fuel
- Relatively large negative temperature coefficient in high output power reactor
- Reduction of mechanical control
- Use of readily available fuel materials, namely highly enriched and natural uranium.

Unlike some other reactor types capable of delivering large amounts of energy, the seed and blanket concept does require highly enriched material. But where diffusion plant facilities are available this is no particular disadvantage and, moreover, the quantity of enriched fuel is small, accounting for only 45% of the U^{235} in the reactor.

Since the reactivity of the seed and blanket reactor is determined almost completely by the seed reactivity, it is possible to use control rods in the seed only. The temperature coefficient is also determined almost exclusively by the seed. Consequently, the water to non-water ratio in the blanket can be adjusted to get maximum blanket power. In addition, the power level of the reactor can be conveniently controlled by changing the steam-valve setting. Since other types of high-power long-life reactors have larger cores (and, therefore, smaller neutron leakage), they have difficulty getting large negative temperature coefficients.

One and two-dimensional few group diffusion theory calculations showed that in general the power distribution in the seed and in the blanket was a function of the rod program. The sharing of power between seed and blanket was found, however, to depend only on the k_{eff} of the core.

Typical radial distributions of the fast and thermal flux are shown in Fig. 2. The fast flux has a peak in the seed and falls off in both the inner and outer blankets. The thermal flux at the center of the blanket is low, rises to a peak in the blanket near the seed, dips in the seed, peaks again in the outer blanket and falls off fairly rapidly until it reaches the water reflector outside the blanket. The shape of the flux in the seed depends strongly on the loading. For heavier loading than that used in the first PWR seed, the slight rise in the thermal flux at the center of the seed tends to disappear and the flux dips even more strongly. For lighter seed loadings, such as encountered later in the seed life, the peak at the center of the seed develops fully and thermal flux shape approaches that of the fast flux. The blanket-power fraction is predicted, using flux distributions of the type shown in Fig. 2, to be 0.536 at the beginning of life for equilibrium xenon. Preliminary measurements at Shippingport, using the flow- and temperature-rise instrumentation, indicate that the power sharing is about as predicted.

. . . Looking Ahead to the Next Core

Even as PWR Core 1 was proudly being eased into position, Shippingport designers were already busy with plans for a second seed for Core 1 and a whole new Core 2. The Core-1 second seed is being designed for approximately 1,500 hours longer life than the first seed. Core 2 will have a lifetime energy output much higher than the design value for Core 1. The Core-2 goal is 100 Mw (gross electric with four coolant loops) and 10,000 equivalent full-power hours for the first seed; the corresponding figures for Core 1 were 67 Mw (gross electric for three loops) and 3,000 equivalent full-power hours for the first seed.

The higher performance goals call for new fuel-element designs. The new seed elements for both Core 1 and Core 2 will continue to be uranium-zirconium-alloy plates but will be more heavily loaded with U^{235} and will contain a burnable poison such as boron. In Core 2 the blanket and seed fuel-element assemblies will be lengthened and the fuel more finely divided. At the moment a flat UO_2 plate is being considered to replace the UO_2-rod blanket elements in Core 1.

Mechanical hardware improvements will also be made in the new design. For example, ways are being explored to simplify the instrumentation connections through the reactor vessel.

Lifetime calculations during a given seed reactivity lifetime were performed using a one-dimensional burnup-calculation machine program (CANDLE).

Studies were made in which new seeds were inserted successively into a given blanket. These studies, carried through for at least three seed lives with a single blanket, indicated that the average blanket-power share falls slowly, being still essentially 50% during the last seed life. The blanket k_∞ increased slightly during the first seed life and then declined. For the remaining seeds the blanket k_∞ fell steadily but appeared to approach an asymptotic value. During a given seed life the power distribution tends to shift from the seed to the blanket because of the fuel depletion in the seed. This effect is most pronounced, however, in the first-seed-reactivity lifetime where approximately 9% of the total reactor power shifts from the seed to the blanket during the reactivity lifetime of the seed. Although the design lifetime for the first PWR seed is 3,000 hours at 67 Mw gross electrical output, lifetime calculations indicate it may last as much as twice as long as the design lifetime. During this time an average of 58% of the total reactor power will come from the natural uranium material. Through the use of several seeds in a given blanket it is quite practicable from a reactivity and power distribution standpoint to irradiate blanket material to an average burnup of greater than 15,000 Mwd/t.

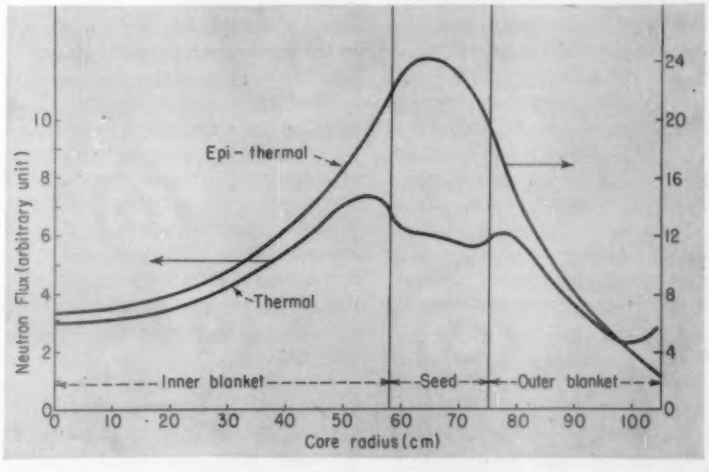


FIG. 2. Radial neutron-flux distribution calculated for start of core life

Fuel-Element Design

With the choice of the seed and blanket type of core, the paramount question facing the designers of PWR Core 1 was how to provide high-integrity blanket-fuel elements containing large amounts of natural uranium. Natural uranium, in the form of an oxide (UO_2), was selected because it has the excellent nuclear properties of the pure element, is inert in high-temperature water, has a very high melting point, and was shown by in-pile tests to be satisfactory from a radiation-damage viewpoint at high burnups.

Blanket element. The blanket element consists of a Zircaloy-2 tube with

end caps and 26 UO_2 pellets which form a fuel rod 10¼ in. long with a 0.411-in. dia. No metallurgical bond exists between fuel and the Zircaloy-2 clad. The length was selected to limit the amount of irradiated fuel released into the coolant stream in the event of a failure and to minimize the possibility of hydraulically induced rod vibration. An 11 × 11 array of rods in a square lattice forms the blanket assembly. One rod is omitted from the corner to allow space for an effluent sampling tube.

The flow to each of four different blanket regions is regulated by orifices in the blanket shells below the fuel assemblies. The orificing compensates for spatial variation in heat generation, allowing a significant increase in core performance that would not have been possible in a completely open lattice where regional cross flow could occur.

Complete fuel rod dimensions, clearances, and tolerances are shown in the foldout (facing p. 56). The clearances and tolerances were set primarily to ease manufacture while still satisfying stress and thermal considerations.

Seed element. The problem of the seed element was more straightforward because metallic alloys of highly enriched uranium and zirconium had already given good performance in previous pressurized water reactors. The primary considerations in selecting the flat plate seed element were: (1) efficient removal of the heat; (2) corrosion resistance; (3) neutron economy; and (4) manufacturing feasibility. The module size, control-rod shape and position, and approximate metal-to-water ratio were set by nuclear and over-all core-configuration design. Detailed information is given in the foldout (facing p. 56).

Future trends. The future trends in fuel element design are governed directly by the over-all Core 2 objectives of longer life, greater thermal capability, lower potential cost, and fewer control rods. This means that fuel elements will not only need higher thermal performance but must also hold up under long-term irradiation. For the second PWR core, the lifetimes-power target has been increased by a factor of five. The fuel loadings required to produce this energy will result in somewhat higher power peaks in the seed. To decrease these peaks the core has been lengthened and the spacing between fuel assemblies reduced. Thinner fuel elements will be required to prevent excessive fuel temperatures.

The highly loaded seed also presents an additional problem, that of effective control. This problem is compounded by the desire for fewer control rods. As a result considerable effort is being made to incorporate burnable poisons such as boron in the seed region.

It is necessary to produce as much of the total power as possible from the relatively inexpensive UO_2 blanket fuel to realize the full potential of the seed and blanket type reactor. To do this, a more efficient heat-transfer element than the present relatively large UO_2 rod is required. Of the several alternatives available, a Zircaloy-clad oxide-type fuel plate design appears rather promising. In this element, small wafers of UO_2 made from natural uranium would be spaced by Zircaloy-2 ribs and contained between Zircaloy-2 sheaths. Rods can be made to yield the required thermal performance, but would involve costly miniaturization in diameter and spacing. Tubes theoretically can furnish some advantage over rods, but most of this gain disappears in actual practice when reasonable dimensions and tolerances are considered.

The oxide-plate-type element uses fuel in the form of natural-UO_2 wafers and has the large surface areas and low fuel temperatures necessary to remove the increased heat output of future PWR blankets. Long-life irradiation proof tests of this element and an extensive mechanical test program to investigate oxide-plate structural characteristics are both in progress. Whether or not oxide elements could be used for seed fuel elements remains to be studied. An oxide-seed element might eliminate the potential irradiation growth problem associated with alloy fuels.

Irradiation damage and distortion in metallic fuels is one of the major problems to be overcome in using the present seed-element design in long-life high-performance cores. Total burnup is not the only factor affecting irradiation damage and distortion. Others are type of alloying element, fuel temperature, exposure time, metallurgical history, and fuel element geometry.

A burnable poison, such as B, will be required to achieve effective control early in life with the highly loaded seed and fewer control rods than previously used. The problems of alloying B directly in the fuel are presently being investigated. One of these is determining the effect on fuel growth of the formation of helium from B^{10} during irradiation.

Tolerances. The requirements for accuracy in fabricating fuel elements and their supporting structures arise from two sources. The one is to provide, consistently, the desired conditions of heat removal throughout the core. The other is to provide mechanical devices and systems that are reliable.

In PWR, small variations in fuel-element and coolant-channel dimensions have a significant influence on coolant temperature, heat-generation rates, and temperature drop across the water-film. The changes caused by the various types of fabrication inaccuracies expected in fabrication are expressed as hot-channel factors and are shown in the table.

In practice the factors are applied as multiplying factors to local ideal-design conditions to determine how close design limits can be approached. Thus variations in fabrication may, by causing a sizeable local perturbation, hold down permissable core average heat production. The combination of these effects in a cumulative manner is considered likely and has been demonstrated by test to be a reasonable basis for design.

The need for tight tolerances in the non-fuel bearing components results in part from the compactness of the fuel arrangement. As an instance, one objective in the design of the core-top-grid plate for Core 1 was to achieve a thin web and minimize the space between fuel assemblies. Similarly the space allocated for the control rod in the core is the minimum compatible with reliable operation.

Flexibility in the design, freedom to refuel and rearrange individual assemblies require the successful operation of mechanical devices under remote and often nonobservable conditions. Whereas this resulted in tight tolerances for Core 1, the objective in future cores will be to relax tolerances by simplifying the mechanical design throughout the reactor and auxiliary systems.

Actuating a control rod by a mechanism 25 ft away which is to operate without lubrication and with minimum wear, requires good alignment. To accomplish this simultane-

PWR Hot-Channel Factors

Item	Bulk-coolant temp. rise	Film temp. diff.	Heat flux
SEED			
Engineering parameters			
Flow distribution	1.070	1.056	1.000
Meat thickness variation	1.051	1.128	1.128
Fuel concentration	1.020	1.040	1.040
Meat eccentricity	1.048	1.143	1.143
Channel thickness	1.100	1.106	1.000
Heat transfer correlation	1.000	1.250	1.000
End conduction from fuel	0.95	0.95	0.95
End coolant channel	0.97	0.95	0.95
Combined product	1.218	1.766	1.210
Neutron flux			
Max. to avg.—radial*	1.248	1.248	1.248
Max. to avg.—axial	—	2.00	2.00
Max. to avg.—water hole	1.29	1.29	1.29
Blanket end cap effect	—	1.09	1.09
Combined product	1.610	3.510	3.510
BLANKET			
Engineering parameters			
Flow distribution	1.070	1.056	1.000
Fuel diameter	1.008	1.008	1.008
Fuel concentration (1.01 density variation) (1.002 concentration variation)	1.012	1.012	1.012
Meat eccentricity	1.024	1.028	1.028
Heat transfer correlation	1.000	1.250	1.000
Pitch, bowing, rod dia	1.113	1.139	1.000
Absence of one fuel rod (for FEDAL System)	1.008	1.008	1.008
Cooling effectiveness	1.060	1.048	1.000
Differential orificing	0.870	0.894	1.000
Combined product	1.156	1.489	1.057
Neutron flux			
Max. to avg.†—radial*			
Region 1	1.243	1.243	1.243
Region 2	1.936	1.936	1.936
Region 3	1.816	1.816	1.816
Region 4	.900	.900	.900
Max. to avg.—axial			
Region 1	—	1.77	1.77
Region 2	—	2.00	2.00
Region 3	—	2.00	2.00
Region 4	—	1.77	1.77
Max. to avg.—bundle depression			
All regions	1.238	1.281	1.281
End-cap peaking, All regions	—	1.18	1.18
Combined products			
Region 1	1.539	3.325	3.325
Region 2	2.398	5.853	5.853
Region 3	2.249	5.490	5.490
Region 4	1.114	2.407	2.407
Over-all blanket factors			
Region 1	1.778	4.951	3.515
Region 2	2.770	8.714	6.187
Region 3	2.599	8.174	5.803
Region 4	1.287	3.584	2.544

* The above maximum to average radial factors are for beginning of life conditions. At the end of Seed 1 life, the following factors are expected: Seed: 1.208; Blanket: Region 1, 1.209; Region 2, 2.528; Region 3, 2.338; Region 4, 0.755.

† Average of the entire blanket region.

ously for 32 rods and mechanisms means that these parts, and the components in which they fit, and all components which contribute to their relative positioning be closely machined, fitted and keyed.

Thermal Capabilities

Since the PWR design had to start more than 2 years ago, the thermal characteristics were based on criteria that existed at that time. In essence, the design was developed around the concept that there should be no local boiling at the hot spot of the core during steady-state full-power operation. Furthermore, it was postulated that there should be no bulk boiling in the water leaving the hot channel during anticipated loss-of-coolant-flow transients. Since that time, much data has been obtained both at Bettis and at other Atomic Energy Commission installations that will serve as a solid basis for evaluating the ultimate thermal-output potential of the PWR core. This data will be used in conjunction with data taken with the core instrumentation on the details of power generation in the present core, allowing a comparison of actual characteristics with design parameters. Early in the core life steady-state power will be limited by local fluctuations in loss-of-coolant flow caused by local boiling. These transients are assumed to occur following loss of coolant-pump power. Later in life, however, a more severe limitation is faced in that buildup of plutonium will cause higher heat fluxes in the blanket region adjacent to the seed. The maximum permissible flux is limited by fuel-element failures apparently associated with center-line melting of the uranium oxide in the blanket elements. The value of this heat flux is approximately 500,000 Btu/hr ft^2 for fuel rods with undefective cladding and about 425,000 Btu/hr ft^2 for rods with defective cladding.

FIG. 3. Blanket fuel element assembly for Core 1 consists of 120 UO_2 Zr-clad fuel rods

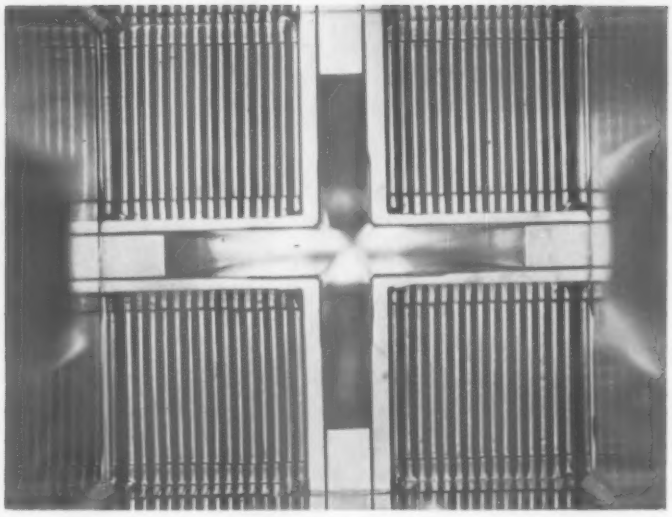


FIG. 4. Top view of seed-fuel-element assembly shows highly enriched U-Zr-fuel plates. Empty +-shaped region is filled by hafnium control rod

The basis for evaluating the ability of the PWR core to produce more power will be two-fold. First, the detailed power characteristics of each of the orificed regions of the core will be measured and compared with design values.

Second, the measured operating heat fluxes and pressure drops will then be related to conditions found to be limiting in the laboratory. Seed and blanket calculations have been done using data for burnout and local-boiling-pressure drop from experiments on rectangular-channel-test sections up to 27 in. in length. Tests on a 6-ft-long-rectangular channel have been completed which confirmed existing burnout and pressure drop correlations. Tests on electrically heated round rods have confirmed that the burnup and pressure-drop correlations developed for rectangular channels also apply to spaced rods with flow parallel to the rod axes.

Until evaluation of operational characteristics and laboratory experiments have been completed the output of Core 1 is being limited to a steady-state net electrical output of 60 Mw with three cooling-loops running. This output is based on limiting conditions in those regions of the core with the most adverse combination of power peaks in both the radial and axial directions. At 60 Mw the maximum seed-element surface temperature is 636° F early in seed life and drops progressively to 594° F at end of seed life. The corresponding maximum surface temperatures in the blanket are 619° F and 636° F respectively.

The initial runs of PWR have shown that the core will be able to override peak xenon for about 3,000 hours of equivalent full-power life—considerably longer than first anticipated. In doing this the amount of power will have to be reduced somewhat because of the unfavorable flux patterns encountered. While analyses are still in progress it appears safe to say that the power capability when overriding xenon early in life will be at least 75% of rated power for a given set of loops in operation. It has already been demonstrated, that this operation does not present any problem in handling normal load transients.

PWR Refueling Program

The original design requirements for Core 1 were that the first seed deliver 60 Mw(e) for 3,000 hr and that the blanket be capable of delivering its share of power for at least two seed lives. Critical experiments, both in the mock-up and prototype, and extensive calculations now indicate that the life of Seed 1 can be extended to approximately 6,000 hr. The design of the second seed, presently in progress, strives for a lifetime in the neighborhood of 7,500 hours.

At the end of Seed-1 life, the spent seed will be removed and replaced by Seed 2. Studies are presently under way to see if the blanket assemblies should be rearranged (for instance, interchanging the inner and outer blanket) to achieve a more uniform burnup or better plutonium conversion.

At the time Seed 1 is removed about 60% of the fissionable atoms in the spent seed will be still left. Higher burnup of the U^{235} can be accomplished by removing selected blanket assemblies and replacing them with Seed-1 clusters. Use of the spent seed in this way not only would extend the life from the original charge of fuel, but would make available a number of spare blanket assemblies that could be used to extend the blanket life beyond two seeds. Analytical and experimental studies are under way to determine the effect of this plan on power capability, shut-down capacity, and radiative heating of the core barrel and structures.

At least once during Seed-1 life and more than once during Core-1 life, it would be desirable to remove a blanket assembly, disassemble it and then inspect it for corrosion, crud deposition, distortion and growth. One or more bundles could be destructively tested for U^{235} burnup, plutonium buildup, and radiation damage of the oxide. Seed clusters could also be removed, but would probably be subjected only to visual inspection and then reused.

Each blanket assembly contains an effluent sampling rake tied into the failed element detection and location (FEDAL) system. It could turn out that no blanket-element failures detectable by the FEDAL system will occur during normal operation. If so, one

way to check the effectiveness of the FEDAL system would be to run tests with an experimental defective fuel element.

Because of the shift in power from the seed to the blanket during the Seed 1 life and because of the Pu buildup in the assemblies closest to the seed, there is a progressive rise in the centerline temperature of the rods in these assemblies as lifetime increases. When Seed 2 is installed consideration will be given, if necessary, to rearranging the blanket assemblies with high Pu buildup to avoid a possible approach to centerline melting conditions at full power.

At the present time, the Core-2 reference blanket-fuel element is a flat oxide plate rather than an oxide rod. Plans for possible proof testing of this type of element in Core 1 have not yet been formulated.

Core Materials

Structure. The early design studies of PWR concluded that the ideal materials for the non-fuel parts of the core should have high corrosion resistance to water at elevated temperatures, have sufficient predictable strength at elevated temperature (600° F), be readily machineable, be weldable, have low absorption properties with a minimum of long-lived impurities and be available in a variety of shapes with a minimum of lead time. The material best satisfying these requirements was found to be type 304 stainless steel. For this reason, type 304 stainless steel is used extensively throughout PWR—as the cladding material in contact with the primary coolant on the pressure vessel and as the base material for the thermal shields, the core cage, the control rod shrouds, the hardware for the seed clusters and blanket assemblies and for the instrumentation tubing and conduit.

Special considerations dictated the choice of more exotic materials for some of the core components. For example in the control-rod-drive mechanism, the tie rod, control-rod shaft and the lead screw were made of type 17-4-pH-stainless steel to provide the extra strength needed during emergency scrams or in the event of a stuck control rod. The lead time for 17-4 pH stainless steel was of the order of 3 months. The finished tie rod, which threads through the connected spline shaft and lead screw, is 258 in. long with an o.d. of 0.625 in. One of the major accomplishments in the manufacture of a spline section was the boring of a 0.656-inch-diameter hole 164 in. in length through a 2-inch-diameter bar with a maximum runout of only 0.012 in. per ft.

Stellite-6 material was used to face the wear surfaces of the shoud bearings and other places at which wear was considered a problem. Haynes-25 material was used for leaf spring applications in the instrumentation systems and as the pin fasteners supporting the top grid and bottom plate in the core barrel. Both of these materials contain large percentages of cobalt (above 50%) and thus become long-lived radioactive sources. The use of these materials to prevent wear and binding by crevice corrosion overrode the radioactivity disadvantage. A main advantage in using Stellite 6 is the ease with which it can be buttered onto the stainless steel base metal. Haynes-25 exhibits high crevice-corrosion resistance when used in combination with type-304 stainless steel and has high ductility and very high strength properties at elevated temperatures.

Control-rods. Hafnium was selected as the control rod material in Core 1 because of its outstanding mechanical properties as well as its nuclear properties. It has good corrosion resistance and is strong enough to carry the stresses imposed by water flow and during scrams. The major disadvantage of hafnium is its unavailability and the high cost of raw material and fabrication.

Since hafnium is a by-product of the zirconium-hafnium separation process, its production is tied in with that of reactor-grade zirconium. As a reactive metal in the same chemical family as zirconium and titanium, hafnium shares many of the fabrication and processing disadvantages with respect to special processing techniques and re-use of fine scrap. Therefore, even apart from the unavailability of the material, relatively high component costs must still be expected with hafnium. Control rod materials cheaper in cost, more readily available, and prospectively lower in fabrication costs are, therefore, under investigation.

One such material (which may be tested during Core 1 operation) is a silver-base alloy containing indium and cadmium that appears to have reactor-control properties almost as desirable as those of hafnium. This alloy has the advantages of good raw material availability, lower cost, ease of fabrication, and direct re-use of all scrap. However, its strength is quite low compared with hafnium and its ability to withstand rigid system-contamination requirements, particularly under conditions of oxygenated water operation, has yet to be proven under actual reactor operating condition.

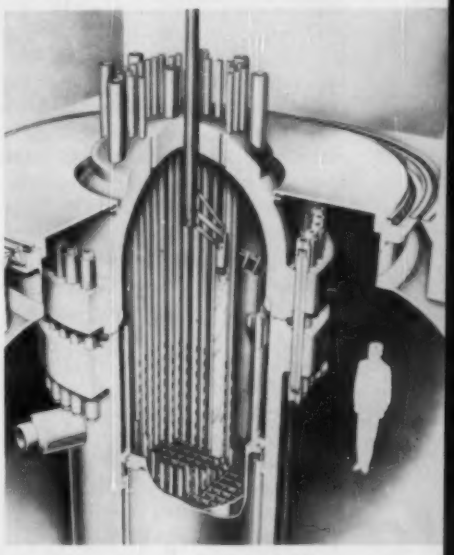


FIG. 5. Remote refueling mechanism removes individual fuel elements without taking off pressure-vessel head

Zirconium. The use of zirconium as the structural material of the fuel elements and assemblies is a primary consideration in PWR economics. The very high cost of this material (see p. 60) keeps it under constant comparison with its chief competitor stainless steel.

A major fraction of the cost of PWR Core 1 is represented by zirconium costs alone. Although the zirconium-sponge-raw-material price was high ($10–$12 per pound) it contributed only a minor fraction to the total Zircaloy costs in Core 1. Most of the metal costs came from other factors such as relatively low yields during fabrication, the present inability to re-use fine scrap, the fabrication procedures necessary to achieve the close tolerances specified and, finally,

the special fabrication procedures dictated by the reactive nature of zirconium material. The close tolerance factor may be equally as severe for stainless steel; in fact, the higher thermal expansion of stainless steel makes welding and heat treatment more difficult and, thus, possibly more expensive than for zirconium. However, on the whole, stainless steel offers a decided advantage over zirconium in material and core fabrication costs.

The main reason for paying the higher price for zirconium lies in its outstanding nuclear properties. To get maximum power from the natural-uranium blanket the materials in the blanket structure must have low parasitic absorption. Zirconium is the only material available that has a sufficiently low capture cross section and, at the same time, excellent corrosion resistance at the PWR operating temperatures. As an example of the deleterious effects of using stainless steel in the blanket, a study was made in which 26% of the zirconium structural and cladding material in the blanket was replaced by stainless steel. Compared with the all-zirconium design, the power sharing in the blanket was reduced by 17% of the reactor power.

The use of stainless steel in the seed is not as prohibitive as in the blanket. The situation here is analogous to that found in highly enriched reactors, in which stainless steel can be used in place of zirconium at the expense of an increase in the fuel loading.

Comparison of the metallurgical and chemical properties of zirconium and stainless steel shows no clear-cut advantage in these areas for either material. On the one hand, the oxide corrosion products of zirconium alloys, unlike those of stainless steel, adhere tightly to the original surface and thus do not contaminate the rest of the coolant system with radioactive material. On the other hand, zirconium, under certain conditions, is subject to embrittlement by hydrogen (one of the corrosion products) whereas stainless steel is not.

Since zirconium is chemically compatible and stainless steel is chemically incompatible with uranium, the former can be alloyed directly from melted cladding-and fuel-component scrap while the latter must be prepared by powder-metallurgy technique. But the zirconium reaction with steam and water is a potential hazard in the highly unlikely event of core meltdown while stainless steel does not have this problem.

Each of the two materials, then, exhibits peculiar advantages and disadvantages that requires compensation in core and plant design. Thus superior nuclear properties and faith that zirconium costs will decrease remain as the primary justifications for using zirconium.

Core Instrumentation

In addition to the plant instrumentation required for the safe and efficient operation of both nuclear and conventional power stations, rather extensive core instrumentation was provided for PWR. Core 1 is, and it is expected that subsequent PWR cores will continue to be, heavily instrumented to provide data for design optimization of future reactor cores and to detect reactor-core malfunctions.

Flow measurements. The rate at which primary coolant flows through 36 selected blanket-and seed-fuel elements is measured using calibrated flow nozzles and modified venturi meters as sensing elements. These seem to be the simplest, most reliable and least expensive of the flow-measuring devices suitable for reactor use. In conjunction with differential-pressure-cell transducers mounted external to the pressure vessel, they have provided data in close agreement (2%) with flow rates determined by analytical methods. It is quite certain that a similar flow sensing systems will continue to be used in future developmental cores.

Temperature measurement. The temperature measurement in Core 1 is done entirely with 304-stainless-steel-sheathed, mineral-insulated (ZrO_2), Chromel-Alumel-thermocouples. A total of 112 thermocouples have been installed. Half of these are $\frac{1}{16}$ in. o.d. and are used along with the flow meters to determine the power produced in selected blanket-and seed-fuel elements. The remainder are 0.040 in. o.d. and are mounted directly within the fuel plates of six seed fuel elements at several axial locations. As a result of difficulties in fabrication and installation, the 0.040-in. couples are not considered reliable.

No flux-gradient instrumentation was included because of the mechanical design problems (interference with through-the-head refueling and additional head penetrations) of providing enough flux-thimble locations.

Fuel-Handling Operations

The reactor may be refueled by any one of three methods—(a) replacement of the complete core cartridge with the vessel head removed, (b) replacement of individual fuel assemblies with the core in the vessel but with the head removed, and (c) replacement of individual fuel assemblies with the vessel head in place using an extraction tool that operates through access ports in the head (see Fig. 5). Because of the time required to remove the vessel head and equipment, instrumentation, etc. associated with it, refueling individual assemblies through access ports in the head has a distinct advantage.

The present fuel handling equipment is designed to operate remotely through a cover shield of water with a system of canals connecting various storage areas and with the reactor pit (see Foldout opposite p. 56). The "wet system" was chosen on the basis of previous successful experience. Possible disadvantages of this system (possible contamination of the canal water and shortening of electrical circuits) have caused consideration of an alternative "dry method" for refueling of individual fuel assemblies. This method would use a shielded cask that could be fitted to an access port in the vessel head.

Actual operating experience so far has pertained only to refueling methods (a) and (b) above. Core 1 was installed as a unit (minus the four seed assemblies that contained the neutron sources) using (a) but with no water in the reactor pit (see Fig. 1). The four assemblies were inserted later using method (b).

The times involved in this first fuel-loading operation were: to install core—one week; to position the reactor vessel head—one night; to seal-weld the head—two days; to connect up the reactor core instrumentation—two months.

Because of the lack of experience, routine refueling times for the core in a hot condition have yet to be established.

PWR Startup, Operation and Testing

CONTROL ROOM at Shippingport: far side of panel has reactor controls; center, turbine-generator; near panel, power-distribution system

OPERATING EXPERIENCE with the Shippingport plant to date indicates that it is very simple to operate—much simpler than an equivalent coal-fired plant.

Principal reason for this is the bare minimum of operator actions required for the reactor and associated systems during power operation. At present the only regular actions the reactor operator must perform are to add makeup water periodically to the water system to compensate for leakage and sampling, and to move control rods in and out to maintain average system temperature at the desired value. These two operations are accomplished by manipulating only three control switches in the control room; the operator will shortly, when the automatic control system is put in service, be relieved of responsibility for maintaining system temperature. From a long-range viewpoint, the reactor operator's role will essentially be to monitor for abnormal conditions as they arise.

In this connection it should be pointed out that a pressurized-water reactor plant is free of many of the problems that arise with a coal-fired steam generator, continually plagued with difficulties in coal and ash handling and in adjusting the unit to operate at maximum efficiency as fuel conditions vary. With a reactor, the only material that must be moved is highly-purified water, and efficiency is a function of systems design that is not significantly modified by mode of operation.

Getting PWR on the Line, Events of the First Month . . .

Dec. 1—Prepared for initial approach to criticality
Dec. 2—Reactor critical for first time at 4:31 A.M.
Dec. 3—Reactor critical; physics tests performed
Dec. 4—Reactor subcritical for testing
Dec. 5, 6—Reactor critical for startup training
Dec. 7, 8—Reactor subcritical for maintenance and checkout of instrumentation
Dec. 9—Reactor precritical checkout started; preparation for physics tests
Dec. 10—Reactor critical for physics tests; started to increase plant temperature toward 525° F
Dec. 11, 12—Reactor critical; continued physics tests and increasing temperature
Dec. 13, 14—Reactor subcritical for tests at 525° F
Dec. 15—Reactor taken critical and turbine-generator checkout started
Dec. 16—Turbine steam-slow-rolled for first time, brought to synchronous speed and operated about six hours, then shut down
Dec. 17—Reactor critical; turbine on motor slow-roll, awaiting decision to synchronize; placed on steam slow-roll at 10:25 P.M.
Dec. 18—Generator breaker closed at 12:39 A.M. and 5 Mw load placed on generator; physics tests and radiation surveys performed at generator loads up to 22 Mw
Dec. 19—Load increased to 32 Mw for testing
Dec. 21—Reactor brought critical, generator synchronized and load increased to 40 Mw, for testing
Dec. 22—Load increased to 54 Mw for testing after correcting governor difficulties
Dec. 23—Load increased to 60 Mw net (full power) at 11:10 A.M. for testing.
Dec. 24—Reactor brought critical, generator synchronized and loaded to maximum—60 Mw net—for 100-hr full-power test
Dec. 25–27—Station operated at full load for testing
Dec. 28—Station load decreased to zero Mw for testing; reactor maintained critical
Dec. 29–30—Reactor critical for testing
Dec. 31—Turbine made synchronous to test governor
Jan. 1–2—Reactor shutdown for testing, plant at 525° F

. . . For a Rundown of Early Operating Problems Turn Page . . .

PWR Early Operating Problems

Dec. 20—At 10:38 A.M. a scram occurred at 32 Mw load when reactor plant 120 V a-c control voltage was lost while attempting to transfer manually from Normal to Emergency source. The 120 V a-c control voltage was being supplied from Normal source, equipped with an inadequately-sized (10 KVA) transformer. Emergency source had been provided with a 25 KVA transformer several days earlier. Subsequent transfers were made satisfactorily.

Dec. 20—At 7:26 P.M. another scram occurred, at 10 Mw load, when transferring the 1A 2400 V bus from the 138 KV transformer to the No. 1 station transformer during startup. Transfer was made with reactor power above 44% and three loops operating. The coolant pump power relay therefore indicated to the reactor controls that coolant flow was not sufficient for existing reactor power level during the period of transfer.

Dec. 23—At 3:39 P.M. reactor scrammed when a coolant loop primary hydraulic valves started to drift closed; they moved $\frac{1}{16}$ in. from open position, while FEDAL hydraulic valve was being tested.

Dec. 24—At 11:34 A.M., 44 Mw load, increased oil pressure in the speed-changer system used to control the turbine governor caused throttle valve to move in; load dropped from 44 to 5 Mw; control rods were manually moved in to correct average temperature in primary coolant, and loaded was recovered in normal manner. No relief valves popped. *No scram.*

Dec. 28—At 5:10 P.M., at 68 Mw load, turbine throttle valves tripped closed due to loss of condenser vacuum while preparing for normal station shutdown. Reactor followed by temperature coefficient; normal temperature and pressure were recovered immediately by manual rod insertion. Proceeded with planned station shutdown, keeping reactor critical for testing. No relief valves popped. *No scram.*

Feb. 4—One U-tube heat exchanger removed from service due to leakage—35 gal/hr—from 2 (of 2,500) water tubes. Condition was discovered during a planned shutdown due to increased boiler levels, increased pressure in secondary, boiler level gauge reading.

Feb. 5—At 1:55 A.M., no load, while performing tests on control rod positions for criticality, the scram setting was too low—at 5×10^{-6} instead of 5×10^{-7}, resulting in an accidental scram.

Feb. 7—At 10:20 P.M., during critical tests, no load, a-c control voltage was lost on failure of attempt to transfer from Normal to Emergency source. Cause: dirty relay.

Feb. 17—At 10:24 A.M., while load being reduced from 61 to 44 Mw, turbine No. 3 governor valve sheared its shaft. No reaction in reactor; plant went smoothly back to 53 Mw. New governor valve being made; meanwhile plant running on Nos. 1, 2, 4 governors with No. 3 closed.

Feb. 18—At 1:03 A.M., while making preparations for taking the turbine off the line, a repetition of the Dec. 20 evening incident occurred—operators tried to transfer a station service bus with the reactor above 44% power—and a scram again resulted.

Feb. 19—A crack occurred in the valve operating system piping; repairs have been carried out.

Mar. 2—During night, a low-pressure oil-fired auxiliary boiler for plant heating, quite independent of power plant, blew up. No tubes damaged, but side of building facing river blown out. Cause undetermined.

NOTE: The protection system makes use of bistable magnetic amplifiers for power-and-flow comparison and shutdown action. This circuitry has performed well. It has been called on to function in three instances and has correctly interpreted the information presented. Two of these were operator error in making coolant pump bus transfers which caused the system to recognize a change from three-loop to two-loop flow while reactor power was above 44% power. The necessity for this shutdown signal does not lie in the danger of the condition itself (power above 44% while flow is reduced to that from two loops), but is necessary to protect against a possible sequential loss of the remaining pumps. Although these scrams were undesirable, they are not felt to be a source of trouble. The third instance was the case of the hydraulic valve drifting off open position, recognized by the protection system as an anticipatory loss of flow and therefore requiring a scram.

Another factor contributing to operational stability in the Shippingport reactor is the small number of continuously-operating auxiliaries whose outage entails immediate reduction in steam output. The only such auxiliaries are the main coolant pumps, rod-drive mechanisms and condensate and boiler feed pumps. The first two are canned-rotor pumps presenting no lubrication problems.

Reactor Control

Such simplicity of reactor operation is not the result of many automatic controls, but rather that a pressurized-water reactor plant is inherently a simpler steam-generation process than a fossil-fuel-fired one. At present the only quantity in the basic cycle automatically controlled is primary system pressure. Conventional proportional plus reset control is used for this, the input being a pressure signal while the output controls the power input to electric heaters in the pressurizer. Ultimately the control rods will be automatically controlled to maintain primary temperature at the proper value. Inputs to this system will consist of an averaged primary temperature as the prime control signal and an inverse neutron flux level derivative as a damping signal.

It may be noted that no mention has been made of controlling the reactor on load swings. The pressurized water reactor is inherently self-regulating on load swings, and no immediate control action is necessary at the instant a load change is made (NU, March '58, 19). This self-regulating ability results from a negative temperature coefficient. When steam demand is increased (or decreased), a resultant decrease (or increase) in average primary temperature occurs, and core reactivity varies to return the system to its original temperature. Principal function of the control rods during operation is to prevent system temperature from drifting as a result of fission-product poisoning and fuel depletion. It is generally necessary to make control-rod adjustments following a load swing, however, because the concentrations of fission-product poisons change with gradually load.

The turbine section of the Shippingport plant is generally similar to other

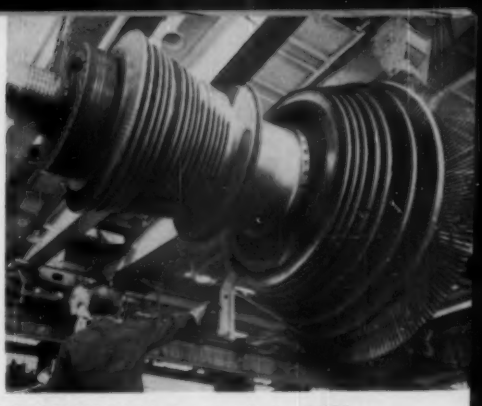
central station units of comparable capacity, the principal difference being that it uses low-pressure saturated steam. Operation and associated problems are very much like those of other steam turbines.

The plant as a whole has proven to be extremely stable and highly responsive to load changes. The most dramatic example of this to date was the plant's response to a turbine-throttle trip at full load due to loss of condenser vacuum; the reactor is not automatically scrammed when this happens. Primarily system pressure increased slightly—from a normal, 2,000 to 2,090 psi—and leveled off with no operator action. Average system temperature started drifting up very slowly and was corrected by minor control-rod adjustment. No additional action was required of the reactor operator, indeed he would have had nothing to do whatever had the reactor been on automatic control. During normal load changes no action is required of the operator.

One problem the Shippingport plant has to contend with in load scheduling not shared by conventional plants is fission-product poisoning, notably by xenon. In later core life, the effect of this poisoning will be to prevent the reactor from being restarted during a certain interval after shutdown; present effects can limit the maximum power level to which it can be raised following shutdown. The reactor is able to override maximum Xe for 3,000 hrs—much longer than originally anticipated or designed; it can handle at least 75% of rated power. No trouble is expected from this quarter in making load changes—this has already been demonstrated in some areas. However, there are still uncertainties concerning the severity of these limitations, and the problem is being studied.

Startup Experiences

The major problem met during initial startup—a continuing problem—was the valve-operating system. Basically, the valves operated by this system are caused to move by air pressure applied to a water flask that transfers the pressure through a pilot valve to one side of a valve piston. When a valve operation is required, 2,700-psig pressure is suddenly applied to the system and considerable vibration of the piping results. Additional hangers and anchors were installed, but future problems may arise as a result of this excessive vibration. Valve drift has also been encountered. When one set of valves is operated, one or more of the remaining valves may move, and during critical operation a scram could, and did, result. Studies on these problems are continuing in the hope that a



TURBINE-SPINDLE being installed. 1,800-rpm turbine can handle 1.4-million lb/hr dry saturated steam

The Shippingport Testing Program

Period I (Sept. 1955–Nov. 1957)
Site Construction and Erection Checkout

Receiving, inspection and cleaning of material and equipment; radiographing and inspection of welds; hydrostatic testing of installed piping and pressure vessels, flushing of fluid systems; calibration of non-nuclear instruments; checking of electrical system wiring, components, and the turbine.

Period II (April 1957–Nov. 1957)
Precritical Systems Testing

All tests necessary to prove integrity of each component: 46 separate test procedures, carried out prior to installation of core, including fluid system leak tests, operation of all rotating equipment, checkout of plant operating procedures, preliminary operation of all systems at plant operating conditions (523° F, 2000 psi).

Period III (2 Dec. 1957–Feb. 1958)
Initial Critical Testing

Physics tests to prove reactor design, obtain proper operation of core and control systems: operational tests of rod control mechanisms, initial calibration of nuclear instrumentation, initial fill of live reactor with water, approach to criticality, determination of reactivity coefficients, operation at low power.

Period IV (Jan. 1958–April 15, 1958)
Testing at Full Power

Testing integrated operation of reactor and turbine generator plant systems, functioning for first time as a utility; functional design capabilities of station are verified for both steady state and transient operation. Includes performance check of over-all plant performance, determination of plant efficiency and capability; core instrumentation used to check calculated performance and power sharing of seed and blanket; all fluid, instrumentation and control systems operated through their complete range; load changes made at maximum design rates and plant performance compared with that expected from design data; performance data for future operation and maintenance reference gathered as well as for practical training for station operating personnel; studies of corrosion resistance of plant materials, activity buildup, shielding effectiveness, decontamination procedures. No portion of plant operated beyond its expected design conditions.

Period V (April 15, 1958—)
Station Capability and Limitation Study

On basis of results of Periods II–IV operational testing, program devised to determine maximum plant capabilities and limitations by exceeding design conditions. Other tests prepared for determination of new methods of operation; for incorporation of useful design changes or developmental equipment in effort to design plant equipment of more conventional design; to check design-calculated performance for accident conditions such as loss of flow, cold water, etc. Will also determine true core performance over life of core; try burning old seed cluster in blanket to test this method for greater burnup; will test oxide-plate blanket assembly (now planned for Core-2); present restrictions on nucleate boiling will be investigated to test this method of increasing power; if no blanket elements fail, a deliberately defective blanket element may be introduced to evaluate usefulness of Failed Element Detection and Location system (FEDAL).

Periodic Testing (*Throughout Plant Life*)

Tests to be repeated at intervals to develop information on activity buildup in reactor plant, changes in core reactivity, power distribution, temperature coefficient, etc.

more reliable valve-operating system can be obtained by changes in the existing design.

Instrumentation and controls were checked out prior to operational testing. Systems were subjected to dummy signals to check outputs. Dummy rod-drive motors were used to perform a complete checkout of the rod-control system. Nuclear instrumentation was checked out using simulated input signals. During installation of the neutron sources in the core, it was found that the BF_3 counters used for source range were too sensitive; adjustments had to be made.

When initial approach to criticality was made Dec. 2 by slow withdrawal of rods, a running plot of the inverse count rate was kept. The only difficulty encountered at this time was an overheated bearing on one of the rod-control-system motor generators.

During initial critical testing, rod worths and temperature, pressure and flow coefficients of reactivity were determined. No particular problems in this phase delayed power operation.

During initial power operation, no attempt at fast startup was made. The reactor plant was brought to operating temperature and pressure, and the turbine put on steam slow-roll. No problems were encountered in increasing the speed of the turbine to 1,800 rpm. Even at low loads, the reactor showed remarkable stability. When trouble was encountered with the turbine governor causing a sudden load decrease of some 40 Mw, the reactor operator had no trouble maintaining temperatures. Again, (see tabulation of operating incidents, p. 71) when the turbine throttle tripped with 68-Mw load, the reactor rode it out smoothly: pressure increased from 2,000 to 2,090 psig and returned to normal. There is no automatic scram provided for this condition, although the regulating system would have called for rod motion had the reactor been in automatic control.

This transient was accommodated by the reactor plant without exceeding either the point at which the coolant system's electrically-operated relief valve operates, or the point at which a high-temperature alarm is actuated. The operator inserted rods at an estimated 30 sec after start of the transient; had he not acted, the electrically-operated relief valve on the steam space in the pressurizer would have had to relieve some pressure at 2,170 psig. Neutron flux level was decreasing rapidly on temperature coefficient effect alone before the operator acted.

A study of this and other transients points up the high degree of stability and the strong self-regulating action possessed by the reactor plant. That these effects are greater than simulator studies and analyses had predicted may be attributed to the following:

1. The size of the plant and its components provides a large amount of energy storage;

2. The automatic spray control in the pressurizer is very effective in reducing pressure surges;

3. The negative temperature coefficient, based on preliminary analyses of test results, is ~20% greater than the value ($2 \times 10^{-4}\,\Delta k/°F$) used in simulator studies.

In the field of automatic reactor protection systems there has been no experience to indicate that important changes should be made in the system as designed, nor is it expected that any such changes will be indicated.

Automatic Protection

The reactor protection system provides automatic power cutback by rod insertion in any of the following eventualities:

- Reactor thermal power ~15% above its capability for the flow existing;
- Startup rate higher than 1¾ decades/min;
- Main generator circuit breaker trip for electrical faults in generator and its directly connected circuits.

It provides automatic scram by rod release in any of the following eventualities:

- 175% power, irrespective of coolant flow conditions;
- Reactor thermal power ~38% above its capability for the flow existing;
- Less than three loops in operation, if reactor power is >44%;
- Less than two loops in service, if reactor power is <44%;
- Coolant outlet temperature > 550° F;
- Coolant pressure <1600 psi (400 psi below design pressure);
- Loss of control voltage

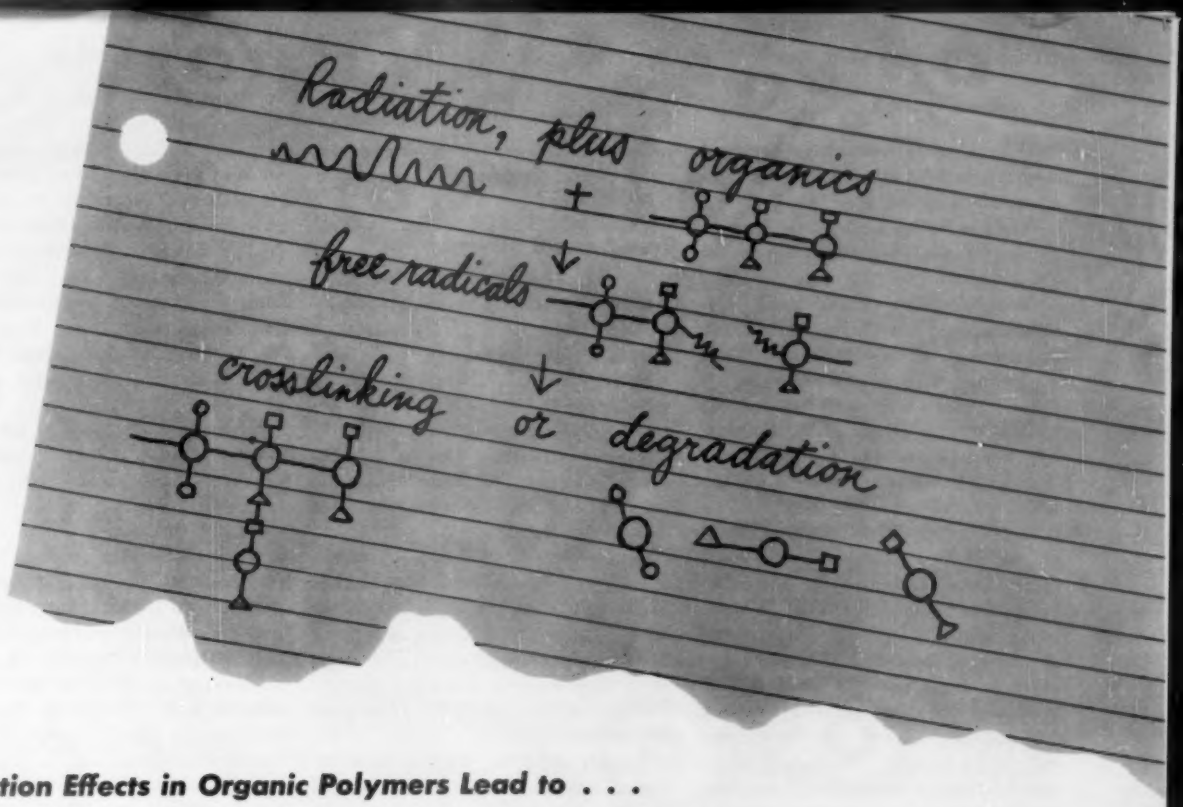
An initial source of spurious protection system operation was the fast startup rate (low reactor period) circuit. Protective action consists of a non-lock-in rod insertion beginning at a reactor period of 15 sec and dropping out at ~20 sec. It is provided on both source and intermediate range nuclear instrumentation chassis since the circuitry for each is identical. It was recognized that the source range instrumentation might produce spurious insertions because of "noise," and that the protection afforded is not essential in the source range. Three or four such insertion signals from circuit "noise" did occur during the early days of critical operation. The signal from the source range instrumentation was removed. The lesson to be learned from this is that it should not have been provided if it was not regarded as necessary.

Those Who Helped

NUCLEONICS' report on PWR was made possible through the cooperation of Rear Admiral H. G. Rickover of the Naval Reactors Branch of the Atomic Energy Commission and the managements of Duquesne Light Company and Westinghouse Electric Corporation. Duquesne assisted NUCLEONICS in compiling information on the significance of PWR for the utility industry and on past and future plant operations. Duquesne personnel involved were: Walter J. Lyman, Vice President, Operations; John E. Gray, General Superintendent of Construction; G. M. Oldham, Superintendent, Shippingport Atomic Power Station; E. M. Parrish, General Superintendent, Power Stations; Charles F. Jones, Reactor Engineer.

Similarly, through the good offices of Charles H. Weaver, Vice President, John W. Simpson, Manager, Bettis Atomic Power Division, and J. C. Rengel, PWR Project Manager, Westinghouse helped NUCLEONICS in gathering information on the significance of PWR for reactor builders and on PWR design and test program. Interviews were arranged with a number of PWR project engineers. In addition, a substantial part of this report is taken from manuscripts especially written for NUCLEONICS by Westinghouse personnel.

To all of the men of Shippingport we of NUCLEONICS express our sincerest thanks.



Radiation Effects in Organic Polymers Lead to . . .

Graft Copolymers— A New Technology?

Better ion-exchange membranes, stronger plastics, better dielectrics are among new and useful materials that may come from today's study of radiation effects in organics, particularly graft copolymerization

By DONALD J. METZ, *Brookhaven National Laboratory, Upton, New York*

RADIATION PRODUCTION of special plastics may be the basis of a new technology. Some commercial plastics are already being processed with radiation to promote crosslinking and improve physical characteristics. Copolymers that have been made in the laboratory with the use of radiation appear to have useful properties as ion-exchange membranes, high-temperature dielectrics, and water-resistant fabrics. Surface grafting, a new technique, offers the possibility of using one plastic to protect another much as plating protects metals.

Changes induced in organic polymers by radiation are generally interpreted in terms of free-radical mechanisms. The reactions that occur depend on the presence or absence of foreign species capable of reacting with the free radicals.

In the absence of such species the principal reactions are crosslinking and degradation accompanied by gas formation and unsaturation. With oxygen present, peroxide and hydroperoxide groups can be formed. These groups are then available for subsequent decomposition, and this leads to changes in the structure and properties of the original material.

If a monomer is present, graft copolymers can be formed. Some of their properties indicate potential technological value. Investigations of them are yet in their infancy, and not enough data exist to specify the effects of varying the many experimental parameters.

Mechanisms

Over-all radiation effects depend on the density of free radicals and the chemical reactants that they encounter

in their medium. These in turn are determined by the nature of the medium, temperature, etc.

When radiation impinges on an organic molecule, predominant processes are ionization and excitation. These occur through direct and indirect interaction with orbital electrons. Ionized and excited species apparently have such short half-lives that they do not enter reactions directly. After charge neutralization, dissociation of a covalent bond occurs almost immediately. The dissociation is homolytic, one electron going with one fragment and one with the other. The resulting active fragments then propagate reactions.

The free-radical nature of the active species has been inferred from such evidence as copolymerization behavior of mixtures of methyl methacrylate and styrene monomers (*1*), inhibition of radiation polymerization by known free-radical inhibitors and the successful explanation of reaction products and kinetics in terms of a free-radical mechanism. More positive evidence has been gathered by electron-paramagnetic-resonance detection of free radicals in irradiated polymers and crystalline monomers irradiated at low temperatures (*2*).

Free-Radical Behavior

Once a free-radical pair has been formed, the simplest reaction is immediate recombination. This is favored if both segments are large or the local viscosity is high. However, if one member of the pair is small—for instance a hydrogen-atom or methyl radical—diffusion apart can be favored over recombination. Once apart, the radicals can be expected to react independently.

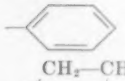
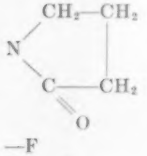
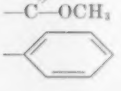
Gas evolution. When a hydrogen-atom or methyl radical is formed, it is likely to abstract a hydrogen atom from a substrate molecule and form hydrogen or methane gas. These and other hydrocarbon gases are usually products of the irradiation of organic substances.

Density effects. Spatial distribution of radicals changes with type and energy of radiation. Variation with type is more significant. The numbers of ion pairs formed per unit of path length by alpha, beta and gamma rays are roughly in the ratio 10,000:100:1. Nevertheless according to measurements made so far, the radiation changes do not appear to depend strongly on radiation quality. This may result from the types of measurements and irradiations that have been made. Thus, alpha particles applied externally will not affect bulk physical properties.

Similarly dose rate does not appear to have a large effect. It can be an important factor if irradiated polymer reacts with its surroundings—for instance with oxygen. The diffusion rate for the foreign reactant to reach reaction sites, produced at a rate proportional to the dose rate, is in competition with reactions occurring in the polymer itself. Recent work on degradation of Kel-F films shows a dose-rate effect (*3*). The usual observation, however, is equal damage for equal energy absorption.

It has recently been reported that a number of polymers that crosslink in bulk degrade in dilute solutions (*4*). This can be explained by assuming that interradical reactions become rare in solutions that are sufficiently dilute.

Common Vinyl Polymers and Modes of Reaction

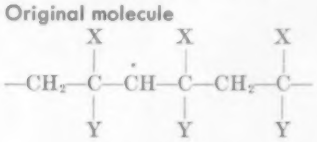
Polymer	*Groups in generic formula* X	Y	*Reaction favored**
Ethylene	—H	—H	CL
Propylene	—H	—CH_3	CL
Methyl acrylate	—H	—$C(=O)OCH_3$	CL
Acrylic acid	—H	—$C(=O)OH$	CL
Styrene	—H		CL
Vinyl pyrollidone	—H		CL
Tetrafluoroethylene (Teflon)	—F	—F	D
Methacrylic acid	—CH_3	—$C(=O)OH$	D
Isobutylene	—CH_3	—CH_3	D
Methyl methacrylate	—CH_3	—$C(=O)OCH_3$	D
α-Methyl styrene	—CH_3		D

* Under irradiation in bulk state; CL = crosslinking, D = degradation.

Free-Radical Reactions

The behavior of the larger fragment of a radical pair is more interesting than that of the small fragment. Let us take a vinyl polymer as an example. As an idealized linear molecule the polymeric radical might look like this:

Original molecule

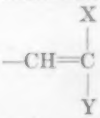


(1)

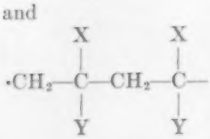
The identities of X and Y for some common polymers are in the table.

Intramolecular reactions available and the products they produce are as follows:

Main-chain rupture

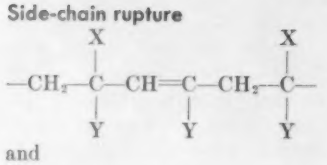


and



(2)

Side-chain rupture

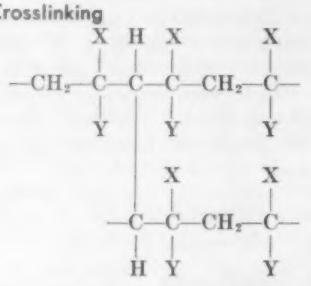


and

X· (3)

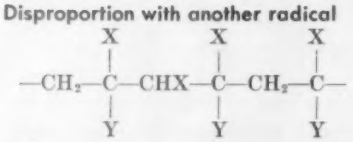
Here are some of the intermolecular reactions that can follow, with their products:

Crosslinking

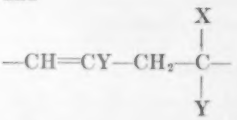


(4)

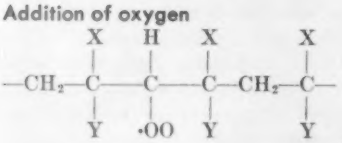
Disproportion with another radical



and (5)

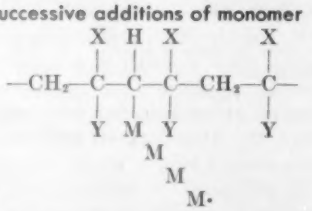


Addition of oxygen



(6)

Successive additions of monomer



(7)

Reactions analogous to monomer and oxygen addition can also occur with the polymeric radical left from main-chain rupture. Alternatively, main-chain rupture can be repeated, leading to successive degradation of the original polymer molecule.

This enumeration of possible reactions is by no means complete. It does, however, depict the formation of many of the species that have been experimentally observed.

First Fruits from Graft Copolymers —Better Ion-Exchange Membranes

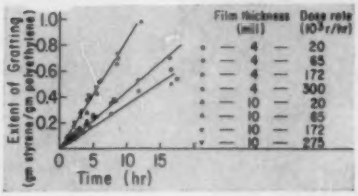


FIG. 1. Grafting of styrene to polyethylene appears to depend on film thickness but not dose rate

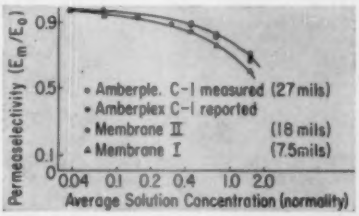

Permeaselectivity (Em/Eo)
• Amberple. C-1 measured (27 mils)
• Amberplex C-1 reported
• Membrane II (18 mils)
▲ Membrane I (7.5mils)
Average Solution Concentration (normality)

FIG. 2. Copolymer exchange membranes have permeaselectivities comparable to currently marketed ones

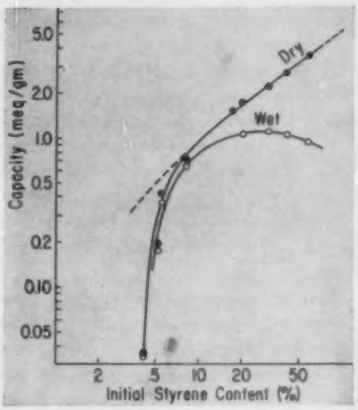


FIG. 3. Ion-exchange capacities of sulfonated styrene-polyethylene films plotted against initial wt per cent of styrene. Decrease in wet capacity above 30% styrene content is ascribed to excessive swelling of films in distilled water

Several promising new materials can be made by graft copolymerization. Most prominent among them are ion-exchange membranes made by grafting styrene onto polyethylene and sulfonating the styrene. An addition of properties occurs. Polyethylene has good tensile strength and flexibility, and it can be extruded or rolled into thin sheets. Polystyrene, on the other hand, is brittle but can be sulfonated to make an ion-exchange medium. Grafting makes a strong, flexible membrane that can be sulfonated (9).

Existing data is not sufficient to determine the effects of various experimental parameters on this process. However, Fig. 1 contains some data obtained in one experiment. Polyethylene films were soaked in benzene at room temperature and dried until their weight remained constant. Then they were covered with styrene monomer and exposed to Co^{60} gamma rays. Nitrogen was used to purge oxygen from a closed system. After irradiation the films were extracted with benzene and dried. Figures 2 and 3 show properties of cation exchange membranes made by sulfonating such films and, for comparison, those of several currently marketed membranes.

Anion-exchange membranes can be made by grafting vinyl pyridine to polyethylene and following with quaternization or by introducing quaternary amine groups into the styrene-polyethylene copolymers. Their properties are similar to the cation-exchange membranes we have just described.

Effects Produced

In the absence of reactive foreign molecules, Reactions 2–5 predominate. When foreign reactants are present, Reactions 6 and 7 become important.

In the absence of foreign reactants degradation and crosslinking undoubtedly occur side by side. One is usually favored over the other in a given polymer under a fixed set of conditions. The competition has been studied for a number of vinyl polymers, and the results are shown in Table 1.

It will be seen that vinyl polymers that principally degrade contain two groups larger than hydrogen on the alpha carbon of the vinyl group. It is thought that for such polymers recombination of two polyradicals is in-

hibited by spatial factors associated with the presence of bulky groups.

The case of Teflon is exceptional since the small fluorine atoms, which not only occupy the X and Y positions but also replace the two hydrogens on the beta carbon atom, probably do not offer any spatial hindrance to radical recombination. Degradation of this polymer generally leads to the formation of quantities of carbon tetrafluoride. This behavior has been ascribed to the great energy difference between carbon-fluorine and carbon-carbon bonds. The former is ~50 kilocalories/mole stronger than the latter.

Recent measurements (*5*) and subsequent calculations (*6*) have investigated the effects of reactor radiations on commercial plastics. High on the stability list are polystyrene and polyvinyl carbazole. They are examples of a type of structure generally known to produce radiation resistance (*7*)—low-molecular-weight hydrocarbons with pendant aromatic rings capable of resonance. Apparently the resonating structure provides a convenient energy sink from which degraded excitation energy can be slowly dissipated in thermal or electromagnetic form.

Incorporation of a mineral filler enhances the radiation stability of the base plastic. Such a filler is generally much more radiation resistant than an organic material. Thus incorporation of asbestos or graphite into a phenol-formaldehyde resin increases the stability of the final product above that of the unfilled resin. However, compounding the same resin with a cellulose filler, which is itself strongly affected, decreases the radiation stability.

With foreign reactants. If foreign reactants are present, we are dealing with Reactions 6 and 7. Of greatest interest are reactions in which polymers react with oxygen or monomers.

Oxygen. If an organic polymer is irradiated in the presence of oxygen, peroxidation and hydroperoxidation can be expected to occur. The extent will depend on the diffusion rate for oxygen, the dose rate, and the nature of the polymer.

The peroxides and hydroperoxides are sometimes fairly stable to thermal decomposition at ordinary temperatures. Over an extended period at room temperature or a shorter one at higher temperatures, however, they will decompose and produce additional crosslinking and chain scission.

Degradation from this effect has been observed in polyethylene (*8*). Irradiation in nitrogen produces a tensile strength that does not deteriorate at 150° C, but samples irradiated in oxygen lose their tensile strength rapidly at the higher temperature. The oxidation effect disappears with higher dose rates or thicker samples.

Curing of polymers may be possible by an oxidation technique. It is known that oxidation in the absence of mechanical stress increases the tensile strength of certain synthetic rubbers. Radicals produced by thermal scission

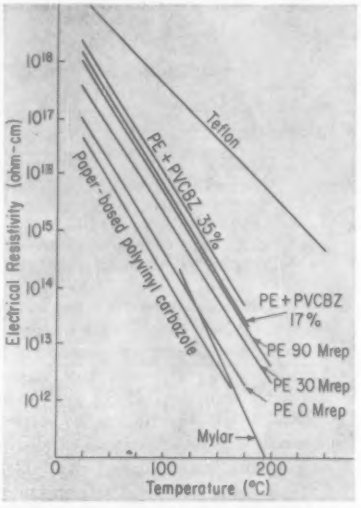


FIG. 4. Vinyl-carbazole–polyethylene copolymer combines good dielectric and mechanical properties. Graph shows resistivity of this and other comparable materials

of peroxide bonds produce carbon-carbon crosslinks. Thus low-temperature irradiation of a polymer in an abundance of oxygen followed by an increase of temperature might produce crosslinking even when the major direct effect of radiation is degradation.

Monomers. Reaction 7 between polymer radicals and a monomer has been the subject of much recent investigation. The reaction produces graft copolymers. If the polymeric radical is a terminal one, formed by carbon-carbon bond rupture, the product is a block copolymer. This is one in which relatively long sequences of each polymer species are linearly connected to one another.

Although much interest is evident in this field and many investigators are working in it, much of the work is as yet unpublished. The work that has been reported has dealt mostly with preliminary investigations of a few specific systems with potentially desirable properties. Not enough attention has been given to such parameters as dose rate, concentrations, temperatures, etc.

Graft Copolymers

Making a graft copolymer consists in grafting a second polymeric chain to an existing polymer molecule. To date no one has determined the spatial relationship between the added polymer species and the base fragment. However the process can be represented as follows:

Starting polymer A

—A—A—A—A—A—

Graft copolymer AB

```
—A—A—A—A—A—A—A—
   B   B   B
   B   B   B
   B   B   B
```

Graft copolymers differ in several ways from ordinary copolymers, which can be represented as follows:

Ordinary copolymer

—B—A—A—A—A—A—B—B—A—

This structure is made up of random sequences of the two monomers. The detailed composition depends on relative reactivities and concentrations of the two. In general, as the *B* fraction increases from 0 to 1, properties trend from those of polymer *A* with a slight impurity to those of polymer *B*.

In contrast the graft-copolymer structure has a sequence of *A* units of polymeric proportions to which are appended, at random, polymeric segments of *B*. Thus the graft copolymer is, in a sense, a loosely bound mixture of two polymers. A true mixture or solution is generally thermodynamically unstable and will separate on standing. Chemical bonding removes the instability.

Grafting with Radiation

There are at least four ways to use radiation to form graft copolymers:

1. A polymer *A* can be dissolved or suspended in pure monomer *B* or a solution of the monomer and irradiated. If the starting polymer is dissolved,

fractionation of the final mixture is necessary to separate the components: unreacted polymer *A*, copolymer *AB* and homopolymer *B*. Fractionation is usually difficult, and separation into absolutely pure components is impossible.

If the polymer *A* is mechanically suspended, simple mechanical operations separate most of homopolymer *B* from the other two components. Most of the remaining homopolymer can be removed by washing with a selective solvent. Occasionally it is possible to remove unreacted base polymer *A* in the same way.

2. One can swell polymer *A* with monomer *B*, irradiate the swollen mass, and extract homopolymer. This method does not waste as much monomer as does the preceding. If the monomer is not sufficiently soluble in the base polymer, the process can be repeated. Generally speaking, as the *B* increases, solubility does too.

3. The base polymer *A* can be irradiated in air or oxygen to produce peroxidic or hydroperoxidic groups along the chains. The system is then immersed in *B* and heated to cause rapid decomposition of the active groups. These become initiating sites for grafting reactions. Depending on the nature of *B*, more or less homopolymer is formed by thermal polymerization.

4. If *A* is irradiated in the absence of oxygen, free radicals are produced and entrapped in the polymer. If *B* is now admitted, preferably with exclusion of oxygen, grafting occurs at the free radicals. Usually a minimum of homopolymer is formed. The main difficulty is in excluding the oxygen.

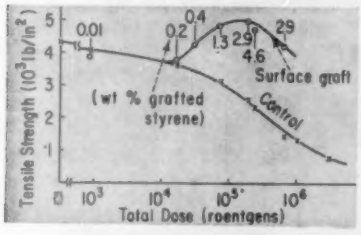


FIG. 5. Styrene grafted on surface of Teflon increases tensile strength up to radiation doses that cause more degradation in the Teflon than strengthening from styrene

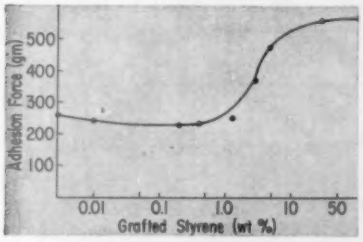


FIG. 6. Adhesion test shows that parting force to remove Scotch Tape increases to value for pure polystyrene as more styrene is grafted on 1-mil Teflon film. Parting rate is 12 in./min

High-Temperature Dielectrics

A vinyl-carbazole–polyethylene copolymer may find application as a high-temperature dielectric (*9*). It is made like the styrene-polyethylene copolymer described in the box on page 75 except that a 10–20% solution of monomer in toluene is used since the monomer is solid at room temperature. The product combines polyvinyl carbazole's low-loss dielectric properties and the flexibility and strength of polyethylene. It is useful above the temperature at which polyethylene is useful and below those at which only Teflon is found to be acceptable.

Data on rate of grafting of this system is rather difficult to interpret, especially at high conversions. One inference may be that grafted vinyl carbazole confers radiation stability and inhibits further grafting. Anomalous behavior between the two lowest-content samples may be due to accumulation of homopolymer in the solution, which had to be replenished from time to time.

A drape test has been devised to measure temperature stability. A strip of film is placed in an air oven with the free end 45 deg above the horizontal. The temperature at which the film bends under its own weight is called the "drape temperature." The increase of drape temperature with increasing vinyl-carbazole content is greater than can be explained by cross-linking of the polyethylene. Figure 4 compares the electrical resistivity of these copolymers and other plastics.

Surface Grafts

Teflon film irradiated in styrene monomer experiences grafting. Since styrene has no appreciable solubility in Teflon, this is doubtless a surface graft. Investigation of two properties confirms this interpretation (*9*).

Figure 5 shows tensile strength as a function of radiation dose. Teflon samples irradiated in air were used as controls. Increase in tensile strength is attributed to a surface layer of styrene. Decrease at higher doses indicates that Teflon degradation is too great to be offset by the surface film. Tests for radiation stability show that films of this kind containing ~10% styrene by weight crumble at 3 megarads just as ordinary Teflon does.

Figure 6 shows the effect on adhesive properties. A 1-in. strip of Scotch tape was firmly rolled on the surface and removed at a parting rate of 12 in./min. In the region of 1–10% styrene there is rapid rise of parting force; above 10% it rises rapidly to the value for pure polystyrene.

Acrylonitrile can be grafted on polyvinyl-pyrollidone film (*10*). The result is a hydrophilic film in a hydrophobic casing. Immersed in water the system swells as water penetrates the outer casing. This is further confirmation of surface-grafting technique.

Grafted on silicone rubbers, acrylonitrile decreases solvent attack (*11*). Increasing amounts of graft change the mechanical properties of the base material from those of an elastomer to those of a plastomer.

Waterproof Fabrics

Commercial Nylon cloth and fibers have been irradiated in a variety of organic liquids with Co^{60} gammas (*11*). Those immersed in styrene and cetane showed markedly reduced water uptake; those in methyl methacrylate, vinyl acetate, and 2,2-trimethyl pentene showed an increase. Since total radiation doses were a few million rads, mechanical properties were adversely affected.

* * *

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Fission-Product Yields from

By SEYMOUR KATCOFF
Chemistry Department, Brookhaven National Laboratory, Upton, New York

FISSION OF A HEAVY NUCLEUS, such as U^{235}, by thermal neutrons results in two fission fragments that recede from each other with a total kinetic energy of about 170 Mev. In general, their masses are unequal—the most probable heavy mass is around 139, and the most probable light mass is around 95. However, products have been found in detectable amounts throughout the mass region 72–161.

The percent probability per fission of forming a given nuclide, or a given chain, is defined as its fission yield. Since the fission fragments are formed with an excess of neutrons, they undergo a series of β^- decays, in a "chain," until they attain stability (Table 2, p. 82).

Fission yields can be determined by radiochemical or mass-spectrometric means.

In the radiochemical method, the number of fissions is usually determined by direct fission counting of a small aliquot of the fissile material exposed simultaneously to the same neutron flux as the main sample. The latter is radiochemically analyzed for the radionuclides of interest. Their absolute disintegration rates can be determined by 4π counting or by gas-phase counting. However, in most of the older work the beta counting was done with end-window G-M counters, and correction to disintegration rates was accurate only to $\pm 10\%$. Frequently the number of fissions was not determined directly in each experiment; only the relative yields of nuclides were measured and Ba^{140} was used as the standard.

The mass-spectrometric method has been applied to measuring fission yields of stable and long-lived isotopes of Kr, Rb, Sr, Zr, Mo, Ru, Xe, Cs, Ba, Ce, Nd and Sm. The absolute number of atoms of each nuclide can be determined by the isotope-dilution technique (*1*). The number of fissions can be determined by measuring the change in the B^{10}/B^{11} ratio in a BF_3 flux monitor irradiated simultaneously in the same neutron flux as the fission sample. Conversion to fissions is effected by use of the known ratio of B^{10}-absorption cross section to the fission cross section. Many of the yields from U^{235} thermal-neutron fission were measured in this way (*2*). In most of the other mass-spectrometric work to date, only the relative yields have been measured.

In compiling these tables, first priority was given to mass-spectrometric data since these are more accurate ($\pm 3\%$) than most of the radiochemical data ($\pm 10\%$). Where

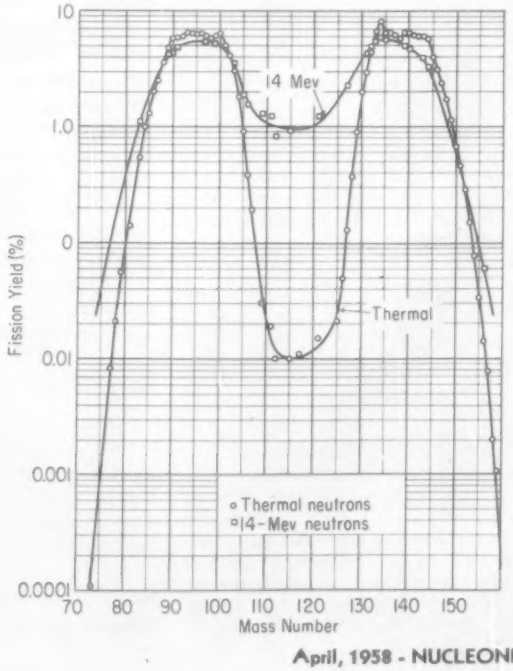
Fission Yields from . . . . . U^{235} . . .

The fission-yield data of Table 2 (p. 82) are plotted versus mass number in the U^{235} curve (circles). The sum of the yields under each peak is very close to 100%, as expected for binary fission. This requirement of summation to 100% each, for the light and heavy groups of fission products, was used as an aid in normalizing some of the data in Table 1 (p. 80). Such a procedure was necessary because few of the fission yields have been measured accurately on an absolute basis.

Small "fine-structure" peaks are clearly shown in some of these yield-vs-mass curves. For U^{235}, these peaks are at masses 100 and 134; they result from a preference for the formation of fragments with a closed shell of 82 neutrons.

The U^{235} curves illustrate the effect on mass distribution of increasing the neutron energy above thermal. The greatest change is the increase in the probability of symmetric fission. For 14-Mev-neutron fission, the increase is about 100-fold; for a fission-neutron spectrum, the increase is four-fold. The other changes are: a small drop in the peak yields and a moderate increase in the most asymmetric modes of fission, i.e., a rise in the wings of the yield-vs-mass curve.

The other two sets of curves show fission-product distributions from thermal-neutron fission of U^{233}, Pu^{239}, Th^{232} and U^{238}.



U, Th and Pu

1—Graphs of Fission Yields (this page)
2—Tables of Fission Yields (p. 80)
3—Tables of U^{235} Decay Chains and Yields (p. 82)

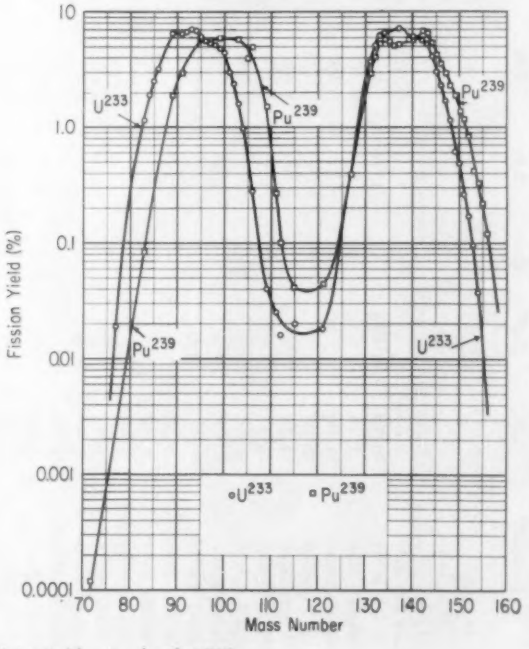
duplicate results were about equally reliable, these were averaged, as indicated in the references to the tables. When one value was considered superior to the others, only that one was selected. No attempt was made to correct any of the values for the transfer of yield from one mass chain to the next lower one by delayed-neutron emission. However, all of the yields have been corrected for known perturbations resulting from neutron capture by the fission products.

It has been shown (*3, 4*) in studies of nuclear-charge distribution in fission that in most cases the last two or three members of a fission-product chain are formed almost exclusively from decay of precursors. In general, only small fractions of the yields of the last two members result from direct formation as primary fission fragments. Therefore a fission yield measured for any of the later members of a chain usually represents the total yield of that chain. In a few cases this rule is violated. For example, the total U^{235} thermal-neutron-fission yield of 86-sec I^{136} is 3.1% (Table 2), but the yield for the entire mass-136 chain is 6.46%. The difference (6.46% − 3.1%) is accounted for by some direct formation in fission of the next chain member, stable Xe^{136}.

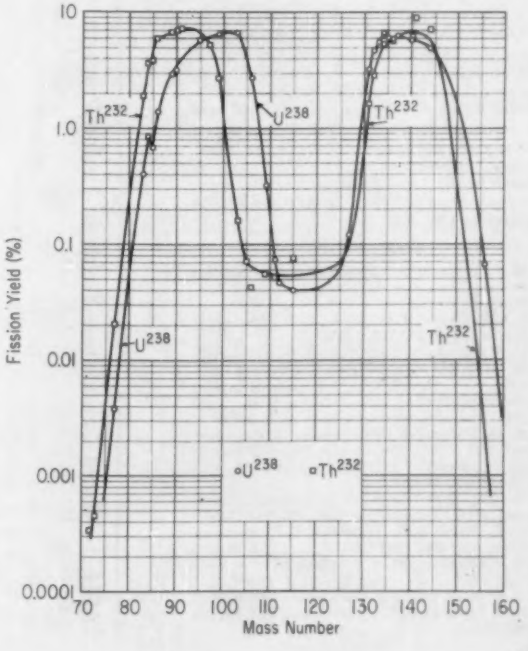
Occasionally the fission yield of a product is lower than that of the corresponding total chain yield because of chain branching to isomers. For example, the total yield of Rb^{85} and of total mass 85 is 1.30% (Table 2), but the yield of 10.3-yr Kr^{85} is only 0.293%. The difference (1.30–0.293%) represents the yield of the isomeric 4.4-hr Kr^{85m}. In some cases, differences between values for different fission products within a chain are due to experimental error.

The thermal-neutron-fission yields of nearly all shielded nuclides are extremely low because these nuclides cannot result from decay of neutron-rich precursors (*3, 4*). The yields (*5*) for 36-hr Br^{82}, 19-day Rb^{86}, 23-hr Nb^{96}, 25-min I^{138} and 12.6-hr I^{130} from U^{235} fission are all about 3×10^{-5} to 5×10^{-4}%. The yields (*5*) of 13-day Cs^{136} are somewhat larger: 0.006% from U^{235}, 0.05% from Pu^{239} and 0.12% from U^{233}. All attempts to detect radioactive products that might result from ternary fission, such as 53-day Be^{7}, 3×10^{6}-yr Be^{10}, 87-day S^{35}, 4.8-day Ca^{47} and 46-day Fe^{59}, have failed (*6*). The upper limits range from 1×10^{-6}% to 4×10^{-4}%. The only well established ternary fission product is He^{4}, which has been observed as an α-parti-

. . . U^{233} and Pu^{239} . . .



. . . Th^{232} and U^{238} . . .



cle in ~0.3% of thermal-neutron fissions of U^{233}, U^{235} and Pu^{239}.

Prior to 1953 most yields from the thermal-neutron fission of U^{235} were measured relative to Ba^{140}, whose yield had been determined absolutely as 6.17% (7). In Table 2 (p. 82) these yields have been renormalized to 6.44% for Ba^{140}. This seems to be a more reliable value obtained from mass-spectrometric data, which is also supported by recent radiochemical measurements. Those yields that were measured relative to Mo^{99} were normalized to a 6.06% value for the latter. (See references *16*, *23* and *51* of Table 2.) A few of the more recent radiochemical yield determinations (e.g., Sr^{89}, Mo^{99}, Xe^{133} and Ba^{140}) are comparable to the mass-spectrometric measurements.

No half-lives shorter than 1 sec are listed in Table 2. Such very short periods would be absent even were it not for the experimental difficulty of identifying them. As Brolley *et al.* (*8*) have shown from studies of gross β-ray and γ-ray fission-product activities, no periods below a few tenths of a second are formed in appreciable yield.

The values for the half-lives and the branching ratios that are given were selected from "Table of Isotopes" by Hollander, Perlman and Seaborg [*Rev. Mod. Phys.* **25**, 469 (1953)]; "Nuclear Science Abstracts" (1953–1957); and a survey of the most recent literature.

* * *

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TABLE 1—Total Cumulative Yields of Fission Products

Fission product	Yield (%)* U^{233} (thermal) (1,2)	Pu^{239} (thermal) (2,3)	Pu^{239} (fast) (2,4)	U^{235} (14 Mev) (2,5)	U^{238} (fast) (2,6)	Th^{232} (fast) (7)	Th^{232} (~8 Mev) (8)
49-h Zn^{73}		0.00012				0.00033	
5.0-h Ga^{73}						0.00045	
12-h Ge^{77}	0.010					0.009	0.022
38.7-h As^{77}	0.019				0.0038	0.020	
2.4-h Br^{83}	0.79	0.085		1.16		1.9	
Stable Kr^{83}	1.14				0.40	1.99	2.7
Stable Kr^{84}	1.90				0.85	3.65	
10.3-y Kr^{85}	0.56				0.153	0.87	
Stable Kr^{86}	3.18				1.38	6.00	
51-d Sr^{89}	6.5	1.9		4.5	2.9	6.7	6.7
28-y Sr^{90}			2.2	4.5	3.2	6.8	
9.7-h Sr^{91}		2.4		4.9		7.2	5.6
58-d Y^{91}		3.0					
Stable Zr^{91}	6.53						
Stable Zr^{92}	6.70						
1.1 × 10^5-y Zr^{93}	7.10						
Stable Zr^{94}	6.82						
65-d Zr^{95}	5.9	5.9			5.7		
Stable Mo^{95}	6.10						
Stable Zr^{96}	5.60						
17-h Zr^{97}		5.6	5.2	5.4		5.2	5.0

Fission product	Yield (%)* U^{233} (thermal) (1,2)	Pu^{239} (thermal) (2,3)	Pu^{239} (fast) (2,4)	U^{235} (14 Mev) (2,5)	U^{238} (fast) (2,6)	Th^{232}§ (fast) (7)
9.6-d Sn^{125}	0.050	0.072		1.34		
91-h Sb^{127}		0.39		2.28	0.12	
8.05-d I^{131}	2.7	3.8		4.3		1.2
Stable Xe^{131}	3.74	2.87		(4.3)‡	3.2	1.62
77-h Te^{132}		5.2		4.2	4.7	2.4
2.3-h I^{133}				5.0		
Stable Xe^{132}	5.10	4.02		(5.0)‡	(4.7)†	2.87
20.8-h I^{133}		5.3		5.4		
5.27-d Xe^{133}		5.27				
Stable Cs^{133}	6.18	(5.27)†		(5.6)‡	5.5	
52.5-m I^{134}				5.3		
Stable Xe^{134}	6.54	5.69		(5.9)‡	6.6	5.38
6.7-h I^{135}	5.1	5.8		4.5		
2.6 × 10^6-y Cs^{135}	>4.9	5.53		(5.7)‡	6.0	
86-s I^{136}	1.7	2.1				
Stable Xe^{136}	<8.9	5.06			5.9	5.65
29-y Cs^{137}	7.16	5.24	6.6		6.2	6.3
84-m Ba^{139}		5.7		5.0		
12.8-d Ba^{140}	6.0	5.68	5.0	4.7	5.7	6.2
Stable Ce^{140}	5.6	(5.68)†				
33-d Ce^{141}		5.2				9.0

Stable Mo^{97}	5.35						
Stable Mo^{98}	5.18						
66-h Mo^{99}	4.8	5.9	5.9	5.17	6.3	2.7	3.1
Stable Mo^{100}	4.40						
Stable Ru^{101}	3.00						
Stable Ru^{102}	2.37						
39.7-d Ru^{103}	1.6	5.8		3.5	6.6	0.16	0.5
Stable Ru^{104}	0.96						
35.3-h Rh^{105}		3.9		1.85		0.07	
1.01-y Ru^{106}	0.28	5.0		1.58	2.7	0.042	0.53
13.4-h Pd^{109}	0.040	1.5	1.9	1.31	0.32	0.055	
7.6-d Ag^{111}	0.025	0.27		1.24	0.073	0.052	0.63
21-h Pd^{112}	0.016	0.10	0.14	0.81	0.046	0.057	
43-d Cd^{115m}	0.001	0.003		0.062	0.003	0.003	
53-h Cd^{115}	0.019	0.038	0.069	0.88	0.037	0.072	0.76
Total 115	0.020	0.041		0.94	0.040	0.075	
3.0-h Cd^{117m}							0.4
27.5-h Sn^{121}	0.018	0.044		1.23			
Stable Ce^{142}	5.6	6.69					
33-h Ce^{143}		5.4			3.9		
Stable Nd^{143}	5.2	6.31					
285-d Ce^{144}	4.1	5.29			3.3	4.9	7.1
Stable Nd^{144}	4.0	(5.29)†					
Stable Nd^{145}	3.0	4.24					
Stable Nd^{146}	2.3	3.53					
Stable Sm^{147}	1.71	2.92					
Stable Nd^{148}	1.15	2.28					
Stable Sm^{149}	0.61	1.89					
Stable Nd^{150}	0.48	1.38					
80-y Sm^{151}	0.26	1.17					
Stable Sm^{152}	0.17	0.83					
47-h Sm^{153}	0.095	0.41	0.48				
Stable Sm^{154}	0.037	0.32					
24-m Sm^{155}		0.22					
15.4-d Eu^{156}		0.12			0.055	0.066	

* For all of the stable products and most of the radioactive ones, the values also represent total chain yields (latter are plotted in Figs. 1–3); "(fast)" refers to fission induced by fission-spectrum neutrons.

† Point of normalization; see corresponding reference for details.

‡ Estimated total chain yield.

§ Additional yield values for ~8-Mev neutrons on Th^{232}: I^{131}, 2-3%; Te^{132}, 2.0%; Ba^{139}, 9.0%; Ce^{144}, 7.2%. See ref. 8 below.

References for Table 1

1. Yields for stable Zr, Mo and Ru (also Zr^{93}) are from E. P. Steinberg, L. E. Glendenin, M. G. Inghram, and R. J. Hayden, *Phys. Rev.* **95,** 867 (1954). Yields for stable and long-lived Kr, Xe and Cs are from W. Fleming, R. H. Tomlinson and H. G. Thode, *Can. J. Phys.* **32,** 522 (1954). Yields for stable Ce and Nd were measured on an absolute basis by M. P. Anikina, L. L. Goldin and B. V. Ershler, Moscow Conference on the Peaceful Uses of Atomic Energy (July, 1955). Relative yields of stable and long-lived Nd and Sm isotopes were measured by E. A. Melaika, M. J. Parker, J. A. Petruska and R. H. Tomlinson, *Can. J. Chem.* **33,** 830 (1955); these were normalized to the data of Anikina et al. at Nd^{143}. The agreement from both sources for Nd was excellent except at mass 144. In this case the yield of Melaika et al. was selected. All other yields from U^{233} fission (except I^{130}) are by E. P. Steinberg, J. A. Seiler, A. Goldstein and A. Dudley (revised by E. P. Steinberg) reported by Steinberg and Glendenin in "Proceedings of the International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 3 (United Nations, New York, 1956). Their Ba^{140} yield was measured absolutely and their other yields were measured relative to this. The yields from most of the other authors were normalized to these data in such a manner as to make the total yield 100% each for the light and heavy fission-product groups.

2. The I^{134} data are from C. W. Stanley and S. Katcoff, *J. Chem. Phys.* **17,** 653 (1949); most of the values for Pd^{109}, Ag^{111}, Pd^{112} and Cd^{115} from fission of Pu^{239} and U^{238} are from Ford and Gilmore *et al.*, LADC-3083; the Sr^{90} yields from U^{235}, U^{238} and Pu^{239} are from B. P. Bayhurst, LADC-3082; the Cs^{137} yield from fast fission of Pu^{239} is from P. Kafalas and C. E. Crouthamel, *J. Inorg. Nucl. Chem.* **4,** 239 (1957), but the value was corrected to a 29-yr half-life.

3. Most of the values for the radionuclides are from data evaluated by E. P. Steinberg and M. S. Freedman "Radiochemical Studies: The Fission Products," C. D. Coryell and N. Sugarman, eds., NNES, Div. IV, Vol. 9, p. 1378 (McGraw-Hill Book Co., New York, 1951). Yields of stable and long-lived Cs, Ce, Nd, and Sm were measured independently by D. M. Wiles, J. A. Petruska and R. H. Tomlinson, *Can. J. Chem.* **34,** 227 (1956), and by L. M. Krizhansky, Ya. Maly, A. N. Murin and B. K. Preobrazhensky, *Soviet J. Atomic Energy* **2,** 334 (1957). The Ce yields of the latter authors were normalized to the 12.8-d Ba^{140} yield; then average Nd and Sm yields from both groups of authors were normalized to the Ce^{144} yield. The Cs yields were related to the Nd yields by the isotope-dilution experiments of Wiles, Petruska and Tomlinson, *op. cit.* Finally, the Xe yields were determined by W. H. Fleming and H. G. Thode, *Can. J. Chem.* **34,** 193 (1956), and normalized to the Cs yields at mass 133. The absolute Ba^{140} yield (5.36%) reported by Steinberg and Freedman (*op. cit.*) has been increased by the factor 1.06 to make the total yields 100% each for the light and heavy groups.

4. D. W. Engelkemeir, M. S. Freedman, J. A. Seiler, E. P. Steinberg and L. Winsberg, p. 1331, Coryell and Sugarman, *op. cit.*

5. G. P. Ford, J. S. Gilmore, *et al.*, LADC-3083; A. C. Wahl, *Phys. Rev.* **99,** 730 (1955); J. Terrell, W. E. Scott, J. S. Gilmore and C. O. Minkkinen, LADC-1463; G. P. Ford, private communication, Dec. 1957. Where the values at 14 Mev are dependent on the corresponding yields from U^{235} thermal fission, adjustment was made to the data of Table 1.

6. Most values were obtained by averaging results from two sources: R. N. Keller, E. P. Steinberg and L. E. Glendenin, *Phys. Rev.* **94,** 969 (1954); and D. W. Engelkemeir, J. A. Seiler, E. P. Steinberg and L. Winsberg, p. 1375, Coryell and Sugarman, *op. cit.* The data are normalized to the Mo^{99} yield, which was measured absolutely by J. Terrell, W. E. Scott, J. S. Gilmore and C. O. Minkkinen, LADC-1463. Data for Kr and Xe are from R. K. Wanless and H. G. Thode, *Can. J. Phys.* **33,** 541 (1955). The Xe yields were normalized to the Te^{132} yield. Cs^{138} and Ce^{144} yields were derived from ratios to Cs^{137} measured by R. H. Tomlinson (private communication).

7. Most values are from A. Turkevich and J. B. Niday, *Phys. Rev.* **84,** 52 (1951); where these were dependent on the corresponding yields from U^{235} fission, adjustment was made to the data of Table 1. Kr and Xe yields measured by T. J. Kennett, H. G. Thode, *Can. J. Phys.* **35,** 969(1957).

8. A. Turkevich, J. B. Niday and A. Tompkins, *Phys. Rev.* **89,** 552 (1953).

TABLE 2—Decay Chains and Yields from Thermal-Neutron Fission of U^{235}

Bold-face underlined numbers give experimental fission yields. Last fission yield along any chain usually represents total chain yield. Lower values for yields of earlier chain members may be caused by (1) direct formation in fission of later chain members, (2) chain branching, (3) experimental uncertainty. Latter accounts for cases where early chain member has higher yield than later one. Where branching occurs, arrows are shown only for decay modes observed experimentally; fraction in each branch is given where known. Parenthese indicate nuclide probably occurs but has not been observed. References for fission yields are cited following chains.

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51. Value 6.44 is average of 6.33 and 6.56 from refs. *9* and *13*, respectively. It is assumed that these mass-spectrometric measurements on Ce^{140} are also accurate measure of Ba^{140} yield since independent yields of La^{140} and Ce^{140} are very small (ref. *19*). Many fission yields have been determined relative to Ba^{140}; these are now normalized to yield of 6.44 for latter. Absolute radiochemical measurements of Ba^{140}, ref. *16* and *52*, give 6.32
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72. $49\text{-h } Zn^{72} \xrightarrow{\underline{1.6\times10^{-5}}} 14.1\text{-h } Ga^{72} \longrightarrow \text{stable } Ge^{72}$ (1,2)

73. $(<2\text{-m } Zn^{73}) \longrightarrow \underset{\underline{1.1\times10^{-4}}}{5.0\text{-h } Ge^{73}} \longrightarrow \text{stable } Ge^{73}$ (2)

77. $54\text{-s } Ge^{77m} \xrightarrow{0.78} 38.7\text{-h } As^{77} \xrightarrow{\underline{0.0083}} \text{stable } Se^{77}$; $54\text{-s } Ge^{77m} \xrightarrow{0.22} 12\text{-h } Ge^{77} \xrightarrow{\underline{0.0031}} 38.7\text{-h } As^{77}$ (3,4)

78. $86\text{-m } Ge^{78} \xrightarrow{\underline{0.019}} 91\text{-m } As^{78} \xrightarrow{\underline{0.021}} \text{stable } Se^{78}$ (3,4)

79. $9.0\text{-m } As^{79} \xrightarrow{\underline{0.056}} \sim 6\times10^{4}\text{-y } Se^{79} \longrightarrow \text{stable } Br^{79}$; $3.89\text{-m } Se^{79m} \longrightarrow \sim 6\times10^{4}\text{-y } Se^{79}$ (5)

81. $56.6\text{-m } Se^{81m} \xrightarrow{\underline{0.0084}} 17.6\text{-m } Se^{81} \xrightarrow{\underline{0.14}} \text{stable } Br^{81}$ (6)

93. $2.0\text{-s } Kr^{93} \longrightarrow (\text{short Rb}) \longrightarrow 7\text{-m } Sr^{93} \longrightarrow 10.5\text{-h } Y^{93} \xrightarrow{\underline{6.45}} 1.1\times10^{6}\text{-y } Zr^{93} \xrightarrow{\sim0.50} \sim 6\text{-y } Nb^{93m}$; $1.1\times10^{6}\text{-y } Zr^{93} \xrightarrow{\sim0.50} \text{stable } Nb^{93}$ (13)

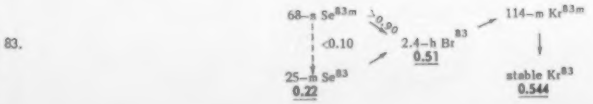
94. $1.4\text{-s } Kr^{94} \longrightarrow (\text{short Rb}) \longrightarrow \sim 2\text{-m } Sr^{94} \xrightarrow{\underline{5.4}} 16.5\text{-m } Y^{94} \xrightarrow{\underline{6.40}} \text{stable } Zr^{94}$ (13,21)

95. $65\text{-d } Zr^{95} \xrightarrow{\underline{6.3}}$ (0.02 → 90-h Nb^{95m}; 0.98 → 35-d Nb^{95}) $\xrightarrow{\underline{6.27}} \text{stable } Mo^{95}$ (13,22)

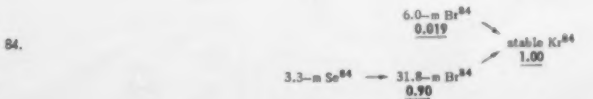
96. $\text{stable } Zr^{96}$ $\underline{6.33}$ (13)

97. $17.0\text{-h } Zr^{97} \xrightarrow{\underline{5.9}}$ (0.98 → 60-s Nb^{97m}; 0.02 → 73-m Nb^{97}) $\xrightarrow{\underline{6.09}} \text{stable } Mo^{97}$ (13,16,22)

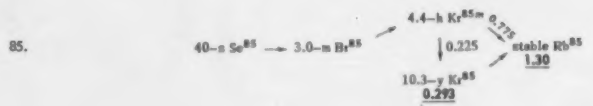
98. $\text{stable } Mo^{98}$ $\underline{5.78}$ (13)

83. 

(7–11)

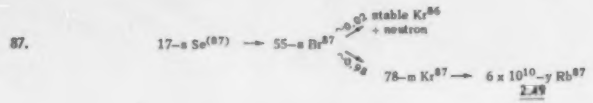
84. 

(9–12)

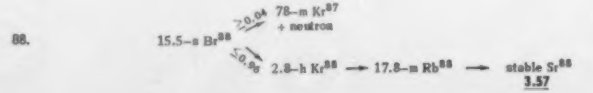
85. 

(9–11)

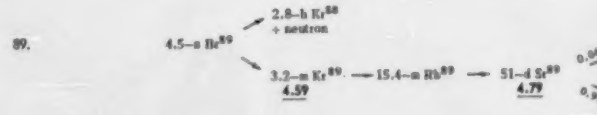
86. stable Kr^{86} 2.02 (9–11)

87. 

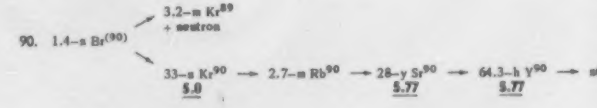
(9,15)

88. 

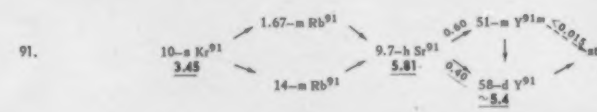
(9,13)

89. 

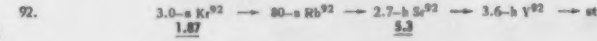
(14,16,17)

90. 

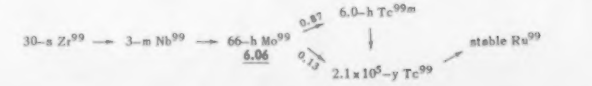
(9,13,14,18,19)

91. 

(13,14,17,18,19)

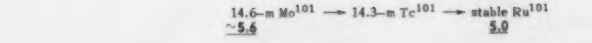
92. 

(13,14,20)

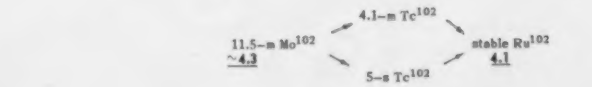
99. 

(16,23)

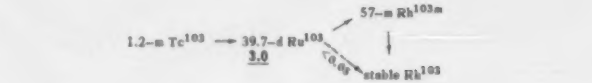
100. stable Mo^{100} 6.30 (13)

101. 

(13,24)

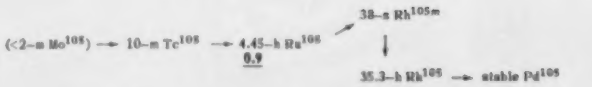
102. 

(13,24)

103. 

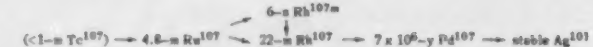
(25)

104. (<2.5–m Mo^{104}) → 18–m Tc^{104} → stable Ru^{104} 1.8 (13)

105. 

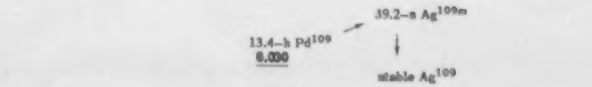
(24,26)

106. 1.01–y Ru^{106} 0.38 → 30–s Rh^{106} → stable Pd^{106} (13,25)

107. 

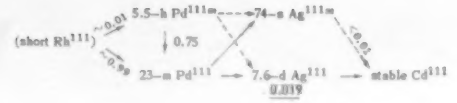
(27)

108. (<1–m Tc^{108}) → 4.4–m Ru^{108} → 18–s Rh^{108} → stable Pd^{108}

109. 

(28)

TABLE 2—Decay Chains and Yields from Thermal-Neutron Fission of U^{235} (cont.)

111. 

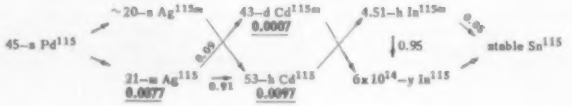
(28)

112.

(28,29)

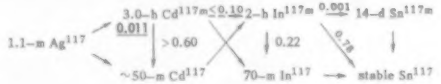
113.

114.

115. 

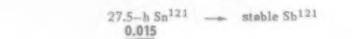
(30)

116.

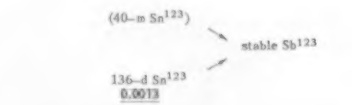
117. 

(31)

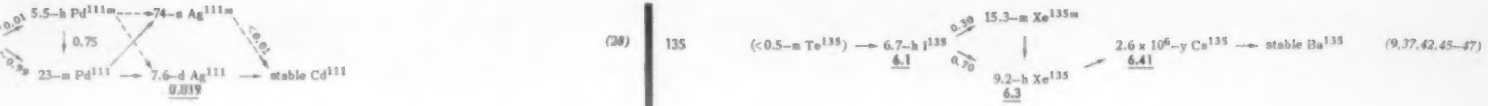
119.

121. 

(32)

123. 

(33)

135. 

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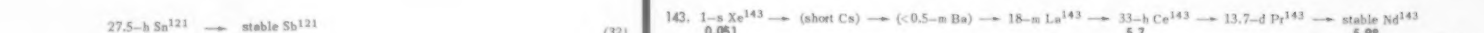
143. 

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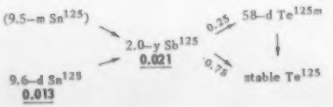
125. 

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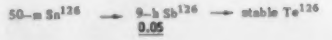
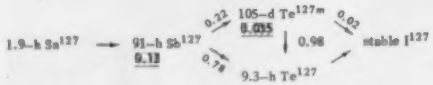
126. 

127. 

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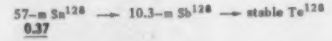
128. 

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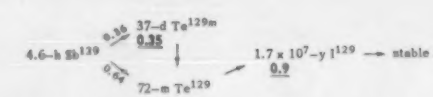
129. 

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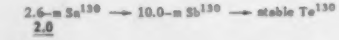
130. 

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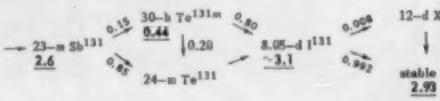
131. 

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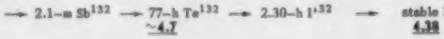
132. 

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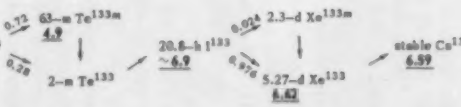
133. 

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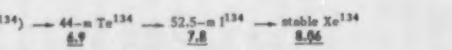
134. 

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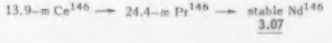
146. 

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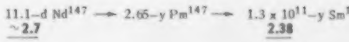
147. 

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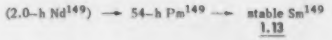
149. 

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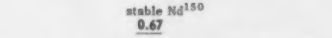
150. 

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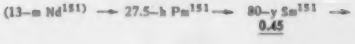
151. 

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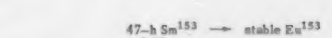
153. 

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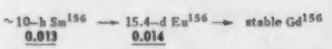
156. 

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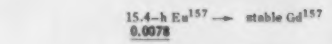
157. 

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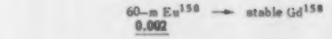
158. 

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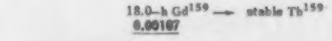
159. 

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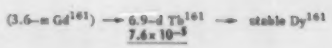
161. 

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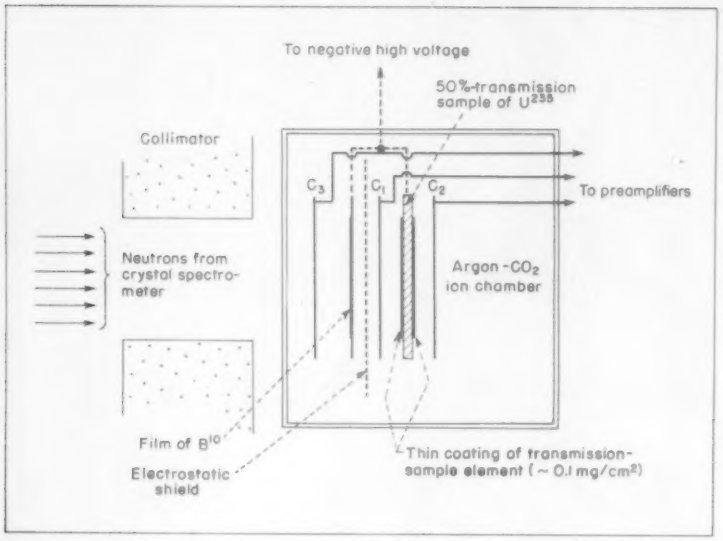


FIG. 1. Three-channel alpha-fission counter for measuring capture-to-fission ratio of fuel. C_1, C_2 and C_3 are collecting electrodes

Three-Channel Alpha-Fission Counter

By F. A. WHITE and J. C. SHEFFIELD
Knolls Atomic Power Laboratory, Schenectady, New York

The three-channel, alpha-fission counter described here was developed for cross-section measurements to determine the variation in the capture-to-fission ratio of fuel at low neutron energies (*1*). It has been used for other relative cross-section measurements (*2, 3*) and is presented for possible applications in other beam experiments.

The argon-CO_2-filled fission counter incorporates three collecting electrodes (see Fig. 1). The incident neutron beam first strikes the boron-10 film; the resulting ionization pulses collected on electrode C_3 indicate beam intensity. The fission rate of the sample is determined by the fission of the thin sample coating and the pulses transmitted by channel C_1, and the absorption cross section is given by the difference between channels C_1 and C_2 corresponding to the fission rates of the two thin-sample coatings.

The counter is especially useful when variations in neutron-beam intensity must be normalized. Such cases arise with experiments utilizing neutron crystal spectrometers and neutron choppers where neutron energies are known but variations in neutron flux occur during long periods because of changes in reactor-power level. Relative rather than absolute beam intensity is measured by placing a parallel-plate B^{10} counter directly in front of the twin fission counter. This arrangement allows a $1/v$ normalization of the beam strength from the number of observed alpha pulses.

The counter has been used as a

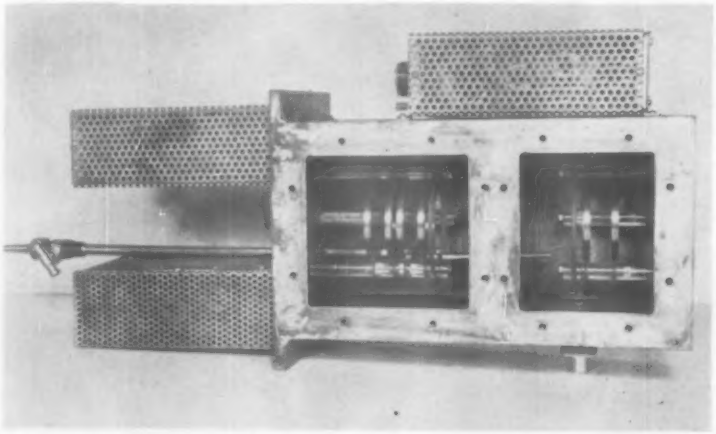
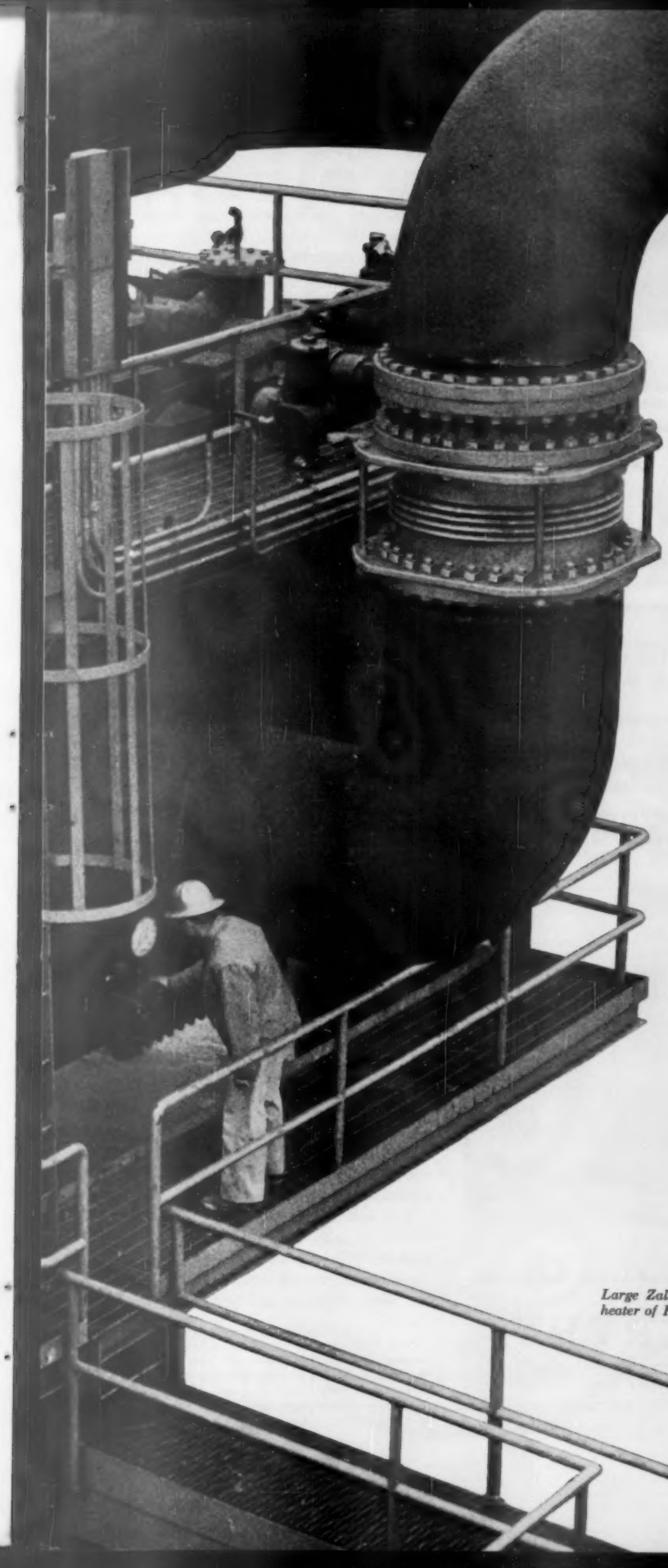


FIG. 2. Top view of fission counter; preamplifiers are attached. Boron and sample portions are separated by 2-mil Al electrostatic shield but have common housing and filling gas



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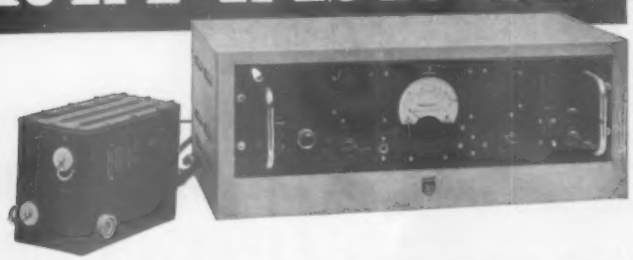

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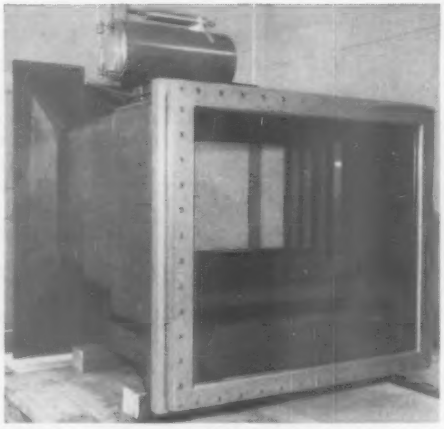

Originators of heavy lead glass

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neutron detector for cross-section measurements in which the sample is inserted into the neutron beam before it enters the chamber. Here, the output pulses from the two fission counters can be combined to double the counting rate. The design also makes provision for inserting the sample between the fission counters as shown in Fig. 1. C_1 and C_2 are the collecting electrodes and the two sample foils are located back to back between them. Variable thicknesses of fuel sample can be inserted between the thin foils.

The sample foils were sputtered on 2-mil aluminum to a thickness of ~0.1 mg/cm² and uniformity of better than 3%. The transmission sample is then essentially sheathed by 2-mil aluminum so that the fission fragments cannot escape. The thin film of B^{10} was also deposited on 2-mil aluminum by the same sputtering technique.

It is clear that if the number of neutron-induced fissions in the two fission counters are to be used to measure the true absorption of a sample placed between them, one assumes either an incident neutron beam that is uniform, or guarantees the uniformity of the fission-foil detectors.* In general, the assumption of a uniformly intense neutron beam cannot be justified. Thus, a technique was developed for sputtering U, Pu and enriched boron from a central 50-mil wire cathode of these materials to a concentric cylinder of aluminum foil of a few centimeters radius. Krypton was used as a sputtering gas and the resultant foils were acceptable from the standpoint of uniformity of deposition and adherence to Al. The aluminum foils were then mounted on rugged foil-holder rings as shown.

Quantitative determinations of the relative weights of the thin fission foils were made by isotopic dilution with a mass spectrometer and standard techniques.

The counter is shown in Fig. 2. Not shown is a 2-mil aluminum window that separates the two portions of the chamber to prevent contamination of the boron counter and serves as an

* An alpha counter has been designed for measuring the uniformity of the alpha-emitting foils. It can be adapted for high or low geometry depending on sample activity—in either case, the uniformity can be measured to ±1% exclusive of statistical error.

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electrostatic shield. All the counters are enclosed in a single housing and so have a common filling gas. Changes in counter sensitivity were determined by observing the number of alpha-particle "pile-up" pulses as a function of discriminator-bias voltage with either fission chamber.

Since the fission process produces large ionization pulses, good discriminator-bias plateaus are easily obtained, and the usual electronic circuitry is adequate. An indication of the bias plateau of the B^{10} counter can be seen in the pulse-height-differential curve shown in Fig. 3. A stability test that measured the ratio of fission counter to B^{10} counter counting rate indicated a standard deviation from the mean of less than $\pm 0.4\%$ for a period of ten days.

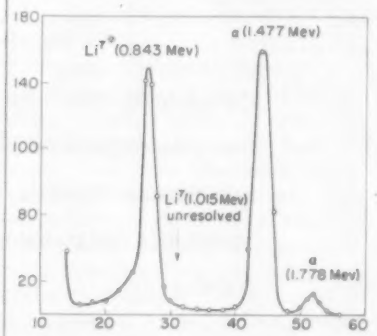

FIG. 3. Pulse-height distribution curve for boron-10 foil in parallel-plate ion chamber

An interesting feature of the boron counter is that it was able to differentiate not only the Li^7 recoils from the alpha particles, but it also resolved the two alpha groups corresponding to the 94% branching ratio. All three peaks can be seen in Fig. 3. This data was obtained with a single-channel, pulse-height analyzer. The high degree of asymmetry on the low-energy side of the Li^7 differential curve is due to preamplifier noise.

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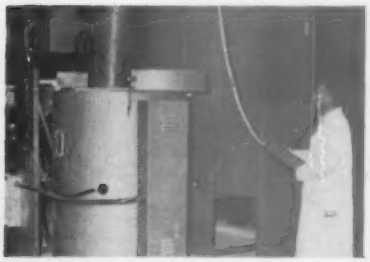

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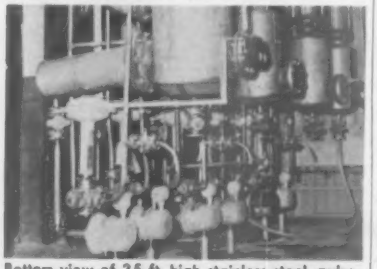

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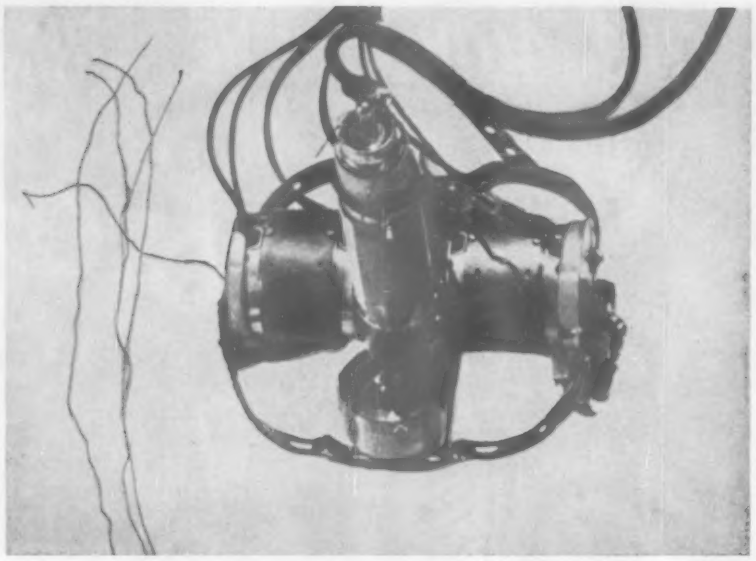

FIG. 1. Free-moving isodose tracer in action—isodose lines are recorded at left

A Free-Moving Isodose-Tracing Machine

By B. C. GREEN
and J. W. T. SPINKS
Department of Chemistry
University of Saskatchewan
Saskatoon, Saskatchewan
Canada

A number of devices have been developed for plotting isodose curves.* Most of these have been "fixed" units, but there would appear to be some advantage in having a free-moving machine that could trace out isodose

*G. A. Mauchel, H. E. Johns, NUCLEONICS **12**, No. 12, 50 (1954).

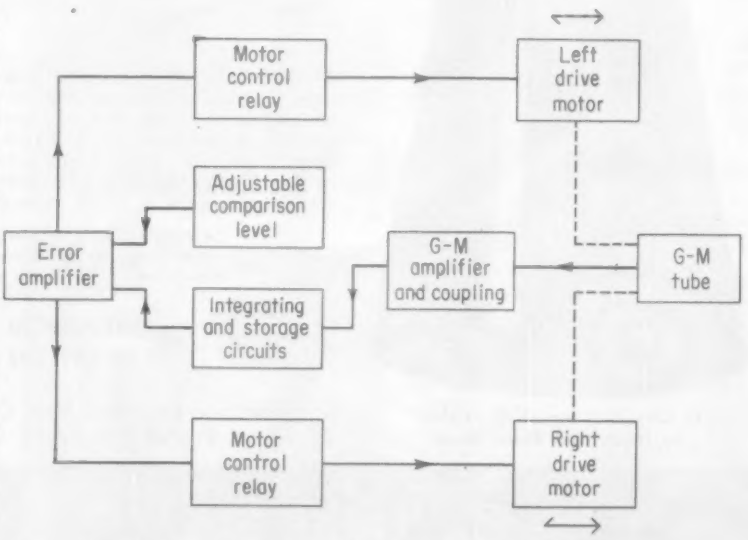

FIG. 2. Diagram of isodose tracer. Relays control direction of motor rotation

(strictly speaking, isocount) curves, e.g., those corresponding to certain radiation levels, in an area contaminated by a nuclear explosion.

An analogous machine called a "crab" had been designed to plot automatically the position of a moving radioactively tagged object such as a wireworm.† A modification of this device was constructed to trace isocount lines (Fig. 1). It consists of a small motor-propelled G-M tube controlled by some of the amplifying and measuring equipment from the tracking unit mentioned above.

The G-M tube is mounted vertically on a small two-wheeled cart. Each wheel is driven by an independently reversible electric motor. A tracing pencil is located on the right bisector of this axle, about 1 in. from the center of the axle. The G-M tube is mounted above this pencil.

The G-M-tube output is fed to a ratemeter type of circuit. The integrated voltage produced by the ratemeter across a storage capacitor was compared with a fixed but adjustable voltage from a potentiometer. The comparison was made in one of the differential amplifiers of the tracking unit.

The relays in the plate circuits of these amplifiers controlled the direction of rotation of the electric motors (Fig. 2).

The control arrangement was such that if the compared voltages were identical, both motors propelled the cart forward (Fig. 3). If the storage-capacitor voltage exceeded the preset voltage, the right-hand motor reversed while the left-hand motor continued running forward. This action holds the center of the axle over a fixed point about which the G-M tube rotates to the right. Provided the

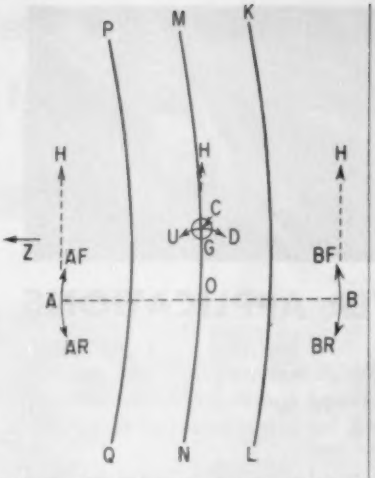

FIG. 3. Control action in isodose tracer. ABC—operating triangle (isosceles); A—left traction point; B—right traction point; C—location of G-M tube and tracing stylus; AH, OH, BH—equilibrium path of A, O and B; AF, O, BR—path of A, O and B when motor at B reverses; AR, O, BF—path of A, O and B when motor at A reverses; CD—path of C when motor at B reverses; CU—path of C when motor at A reverses; G—G-M tube located at C; O—midpoint of AB; MN—isocount line on which G-M counting rate is n counts/min (equilibrium position); PQ—isocount line on which G-M counting rate is $(n + a)$ cpm; KL—isocount line on which G-M counting rate is $(n - a)$ cpm; Z—direction of increasing counting rate

† B. C. Green, J. W. T. Spinks, *Can. J. Technol.* **33**, 307 (1955).

Parts Description for Isodose Tracer

G-M tube	Victoreen 1B85
Motors	Haydon 1/6-rpm type 2200 reversible with 1-in. diameter Rubber-surfaced Meccano pulleys for traction wheels
Adjustable comparison level	Variable voltage, from potentiometer, set equal to that delivered by storage circuit for isocount line desired
Motor-control relays	Single-pole, double-throw, controlled by error-amplifier relays, arranged so that respective motors run forward when error-amplifier relays are open and in reverse when error-amplifier relays close
Error amplifier, Geiger coupling and amplifiers, Integrating and storage circuits	Same circuit as in tracking unit (see reference 2)

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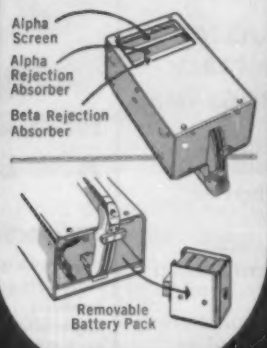

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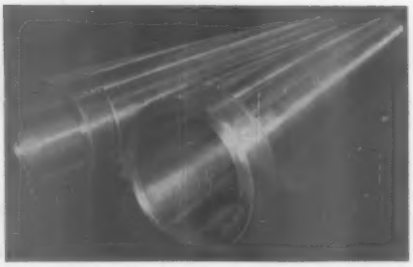

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activity increases to the left, this action is error correcting. Normal forward motion is resumed when the storage-capacitor voltage has dropped to the value of the preset voltage. Conversely, if the storage-capacitor voltage is below the preset value, the left-hand motor reverses and the G-M tube moves to the left.

The cart must be started in the correct direction. This direction is that with the G-M tube ahead of the axle and with the field increasing to the left. The start must be made in

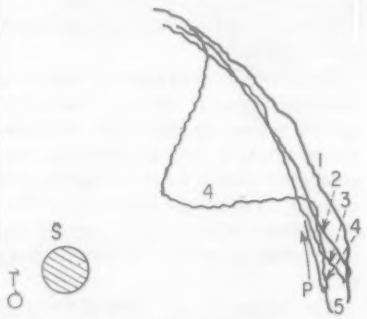

FIG. 4. Isodose tracings. T—radioactive source; S—metal block; P—point of counting-rate check; curves 1, 2, 3 and 5 without shield (lateral drift due to warm-up); curve 4 with shield in place

a field strength that results in a storage-capacitor voltage approximately equal to the reference voltage. Provided these initial conditions are met, the pencil will trace the isocount curve corresponding to the reference-voltage setting. The tracing will follow re-entrant sections.

The over-all control action tends to keep the axle perpendicular to the isocount line it is tracing. The maximum sustained curvature change that can be negotiated accurately has a radius equal to the distance of the G-M tube from the center of the tracing-machine axle.

A few general operational tests of this unit were made. Figure 4 indicates that the unit was able to follow the circular isodose curve about a radioactive source placed on a support and to follow the edge of the "shadow" created by a cylindrical metal shield placed between the radioactive source and the isodose-tracing machine (see also Fig. 1).

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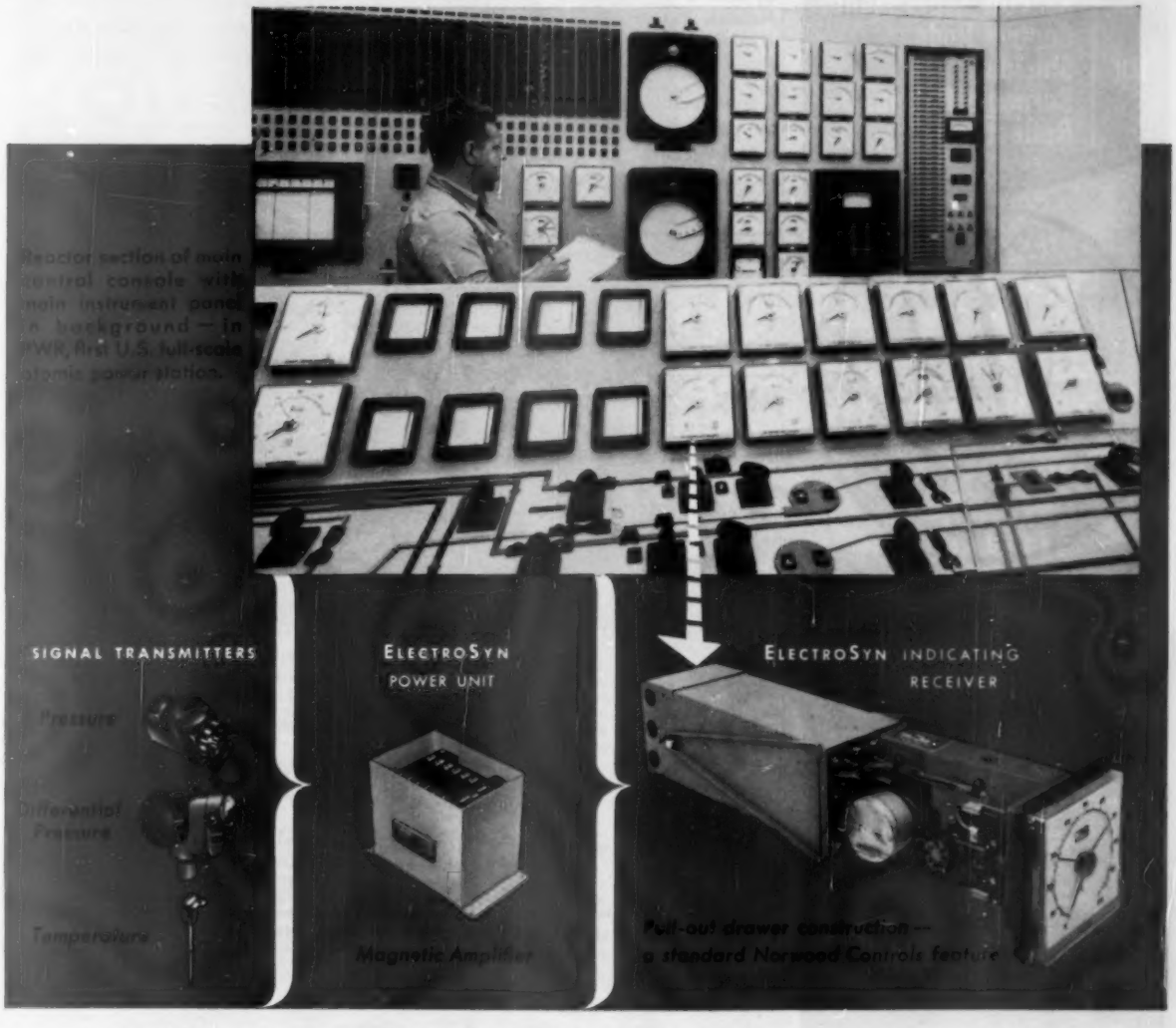

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Plastic Phosphor Matrix for Fast-Neutron Detection

By B. BROWN* and E. B. HOOPER, Jr.†
National Bureau of Standards
Washington, D. C.

Fast-neutron detectors consisting of inorganic-phosphor grains dispersed in a hydrogenous-plastic "button" (*1–8*) have been widely used because of their excellent gamma-ray discrimination. The work reported here demonstrates that organic-plastic phosphors provide buttons with faster light-pulse decay times, greater transparency and in-

* PRESENT ADDRESS: Physics Dept., New York University, University Heights, New York, N. Y.

† PRESENT ADDRESS: Massachusetts Institute of Technology, Cambridge, Mass.

Properties of Phosphors for Fast-Neutron Detectors

Phosphor	*Decay time (sec)*	*Relative light output*	*Index of refraction (η)*	*Comments*
ZnS(Ag)	10^{-7} and 10^{-5}	1.00	2.4	Advantages: Easily obtained and processed; stable Disadvantages: Long decay time; (n,p) and (n,α) reactions at higher neutron energies; high η
KI(Tl)	10^{-6}	0.30	1.687	Advantages: Good η match, efficiency and low-energy response Disadvantages: Slightly hygroscopic; hard to grind; some (n,α) reaction at high energies
NaI(Tl)	0.25×10^{-6}	1.00		Advantages: Good efficiency; excellent low-energy response Disadvantages: Very hygroscopic; hard to grind; some (n,α) at high energies
Plastic				
Polyvinyltoluene base	3×10^{-9}	0.30	~1.6	Advantages: Best η match; highest efficiency; tissue equivalent; very fast
Polystyrene base	8×10^{-9}	0.30	~1.6	Disadvantages: Does not detect neutrons <1 Mev; hard to grind to small grain size

Properties of Plastic Bases for Fast-Neutron Detection

Plastic	*Index of refraction (η)*	*Transparency*	*H/C*	*Fabrication*	*Comments*
Lucite	~1.5	Excellent	~1.3	Mold	Advantages: Available in small grain sizes; transparent Disadvantages: Low η
Polystyrene	~1.6	Good	~1.2	Mold	Advantages: Good η match with many phosphors
Polyvinyltoluene	~1.6	Excellent	~1.13	Mold	
Self-curing plastic mixes				Mix and pour	Advantages: Easy fabrication Disadvantages: Might damage hygroscopic phosphors
Paraffin + light guides		Poor	~2	Heat and pour	Advantages: Good for opaque mixtures

Construction view of one of the steam separating drums at Shippingport during the construction of the plant. In operation, pressurized water from the reactor is circulated through stainless steel tubes in the heat exchangers, where boiler water in the exchanger shell is converted into steam. The steam-water mixture flows upward through risers to the steam separating drum, where the steam is separated, dried and delivered to the turbine generator.

on the line at Shippingport

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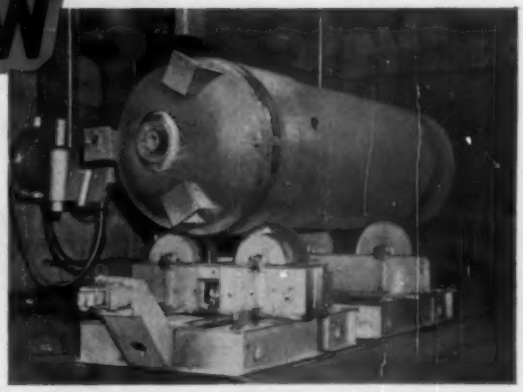

The pressurizer vessel is X-rayed at Foster Wheeler's Mountaintop plant to make sure all welds are flawless. This vessel maintains system pressure and contains system surges. Steam generated by electric heaters establishes and maintains the pressure. During negative surges, additional steam is flashed from the hot water in the bottom section. During positive surges, pressure is reduced by water spray injected into the vessel.

WHEN, on Dec. 23, 1957, the Shippingport Atomic Power Plant first went critical, delivering 60,000 kw to the Duquesne Light Company System in the Pittsburgh area, it opened a new era in the history of power generation.

Significant, too, is the *teamwork* which this accomplishment represents. For it is a joint effort of the Atomic Energy Commission, Westinghouse Electric Corporation, designer and builder of the pressurized water reactor, and Duquesne Light Company, constructor and operator of the turbine generating station.

As a sub-contractor to Westinghouse, Foster Wheeler designed and fabricated two of the four steam generators, each consisting of a heat exchanger, steam drum and interconnecting piping.

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creased neutron-detection efficiency and with mean atomic number closer to being tissue-equivalent. Measurements were also made with inorganic phosphors for comparison. The results are summarized in the table.

These button scintillators work as follows: A recoil proton from elastic neutron scattering can lose most of its energy in a phosphor grain, producing a large light pulse. Secondary electrons from gamma rays, however, lose less energy in a phosphor grain (because of smaller energy loss per unit path) and therefore produce smaller light pulses. Gamma rays can thus be discriminated against on the basis of pulse height. Many neutrons will not be detected since their recoil protons do not pass through a phosphor grain.

Button Preparation

The phosphor particles* were mixed with inert-plastic particles of approximately the same size and molded in a heated hydraulic press. Most of the buttons were $\frac{5}{8}$ in. in diameter by $\frac{5}{8}$ in. thick. Both Lucite and polystyrene media were used, with polystyrene yielding the more nearly transparent buttons. Although the dispersion of the plastic-phosphor particles was never entirely uniform, there were no large clumps of phosphor and no settling.

Some difficulty in obtaining plastic-phosphor particles was experienced, so lathe shavings were ground in a porcelain mortar and sieved to give the desired size. Two particle sizes, one of about 200 μ and the other 44–177 μ diameter, were used. The measurements indicated that buttons with the smaller particles had both higher neutron-detection efficiency and better gamma-ray discrimination. The plastic-phosphor particles appeared to spread about 50 μ because the particles dissolve in the plastic medium.

In the plastic-phosphor buttons, the percentages by weight of the plastic phosphor to inert plastic ranged from $\frac{1}{2}$ to 10%. ZnS(Ag) buttons† were used for comparison with the plastic-phosphor buttons. For the ZnS but-

* The plastic phosphors used were Pilot Scintillator B manufactured by Pilot Chemicals, Inc., Boston, Mass., and Scintilon manufactured by National Radiac, Inc., Newark, N. J.

† The phosphor used was RCA 33-Z-20A ZnS(Ag).

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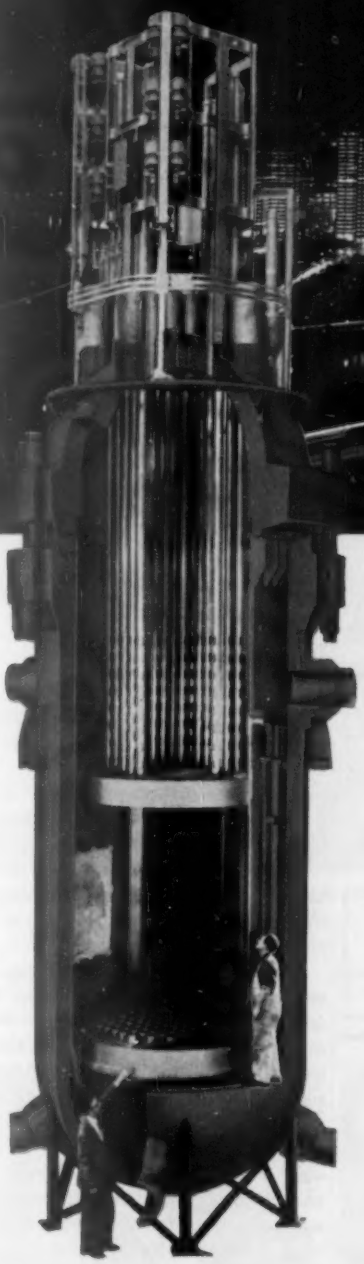

Full-scale cutaway model of 4-story high Shippingport reactor. The reactor vessel, indicated by the colored areas, was designed and built by Combustion.

On December 2, 1957, the country's first full-scale atomic power plant... the Shippingport Station operated by the Duquesne Light Company...went critical. It began producing power December 18 and reached full power output 5 days later. Designed by Westinghouse Electric Corporation for the Atomic Energy Commission, this pioneer nuclear power plant is now in regular operation, supplying electricity to the Pittsburgh area.

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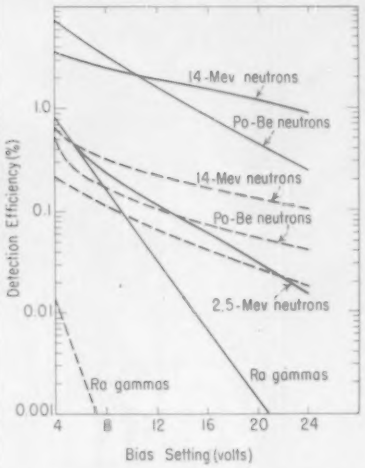

FIG. 1. Response of 3% Scintilon in polystyrene (solid lines) and 30% ZnS in Lucite (dotted lines)

tons, which are more opaque than the plastic-phosphor buttons, an increase of ZnS up to 30% by weight improved neutron-detection efficiency while retaining excellent discrimination against gamma rays.

Test Procedure

The buttons were placed in an aluminum holder with a white Tygon backing and coupled by silicone oil into a 6292 photomultiplier tube. The photomultiplier signal was fed through a conventional preamplifier and a Chase-Higinbotham linear amplifier into a multichannel analyzer, which allowed the simultaneous recording of the counting rate from the button for eleven integral-bias settings.

The buttons were tested at neutron energies of 2.5, 4.5 (Po-Be) and 14 Mev (see Fig. 1). The neutron emission rate of the Po-Be source was standardized by comparison with a standard source. Neutron fluxes obtained from the Van de Graaff accelerator were determined by associated particle counting. For the 14-Mev neutrons, α-particles from the $H^3(d,n)He^4$ reaction were counted; for 2.5-Mev neutrons from the $H^2(d,n)He^3$ reaction, protons from the companion reaction $H^2(d,p)H^3$ were counted.

Test Results

The neutron-detection efficiencies (counts per incident neutron) of some plastic-phosphor buttons were as high as 10% for Po-Be neutrons or roughly

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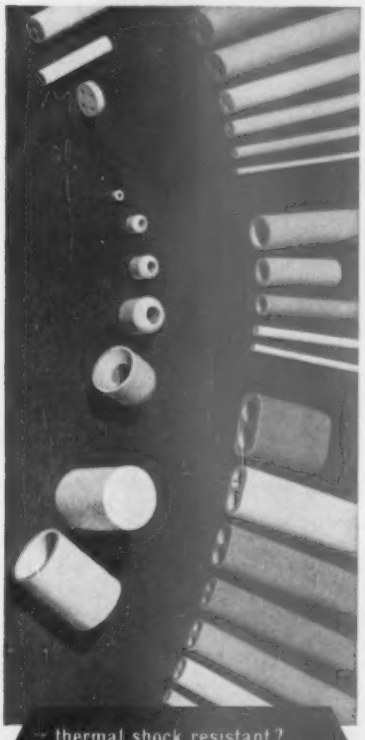

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ten times the efficiencies of the ZnS buttons tested (see Fig. 1). At 0.1–1% neutron-detection efficiency, the plastic buttons had comparable or better gamma-ray discrimination than ZnS.

Because the path length of an electron is so much longer than that of a proton, a thin button gives better discrimination against gamma rays than a thick one. In such a button, high-energy (gamma-ray-produced) electrons would escape from the button without losing all their energy. The opaque ZnS buttons act like thin buttons because the light from the back of the buttons is attenuated before reaching the photomultiplier. For transparent buttons, the size of the button increases the gamma efficiency more than it increases the neutron efficiency, because the electron travels through more phosphor in the larger matrix. A thin plastic-phosphor button would also exhibit low neutron-detection efficiency.

Energy dependence. The neutron-detection efficiencies of the detectors decreased at lower neutron energies because of the low fluorescence efficiency of organic scintillators for low-energy protons.

Gamma-ray discrimination was observed to decrease significantly when percentages by weight of plastic phosphor to inert plastic were greater than 5%.

In the case of pure plastic phosphor, maximum fast-neutron-detection efficiency is ~25% for a ⅝-in. thickness. Maximum gamma-detection efficiency is 2–6%. These efficiencies are dependent on energy and discriminator setting. The detector is more efficient in detecting lower-energy neutrons providing the discriminator is set well below the neutron energy. The estimated maximum neutron-detection efficiencies for the ⅝-in.-thick buttons are 20% for 2.5-Mev neutrons, 15–18% for Po-Be neutrons (4.5 Mev) and 6% for 14-Mev neutrons.

Phosphor grain size and density. A smaller grain size is more efficient for detecting neutrons because the larger surface-to-area ratio of the smaller grains intercepts more recoil protons from the hydrogenous media than do larger grains. However, the grains must not be so small that they are transparent to the recoil protons.

The gamma-detection efficiency, on the other hand, decreases for smaller

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grain sizes. This is because the phosphor distribution is more uniform and the probability of an electron traveling a relatively large path in aligned phosphor grains is diminished.

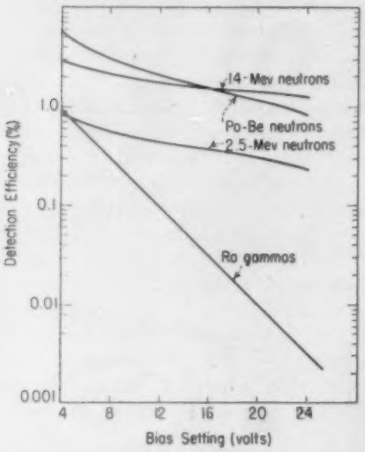

FIG. 2. Response of 30% KI in polystyrene

A higher phosphor density in general increases both the neutron- and gamma-detection efficiencies. If the button is opaque, however, only the portion of the matrix near the photomultiplier remains effective.

Inorganic phosphors. Buttons containing NaI(Tl) and KI(Tl) were also investigated (see Fig. 2 for a typical response). Both KI and NaI buttons are more efficient neutron detectors than ZnS buttons.

At high neutron energies, the plastic-phosphor buttons were more efficient than any of the inorganic phosphors tested. At energies below 1 Mev, the inorganic phosphors produce larger light pulses and in some cases may be more efficient than the plastic-phosphor buttons. It is possible that by combining a plastic phosphor and KI and NaI in a single button a neutron-energy response suitable for neutron dosimetry could be obtained.

* * *

The authors wish to thank Dr. Randall S. Caswell for his many helpful suggestions and advice and Walter Bailey, David Oliver and Willis Doering for operating the Van de Graaff accelerator.

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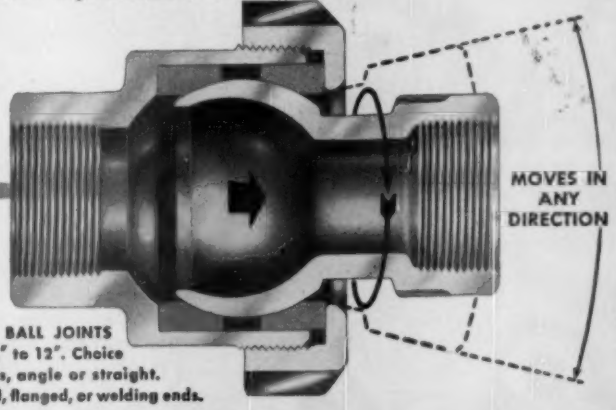

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NUCLEAR ENGINEERING NOTES

Radiation-Resistant Reactor Insulation Reactor designs in which different regions of the core operate at substantially different temperatures are being given serious consideration for a variety of purposes. Included are power reactors with separate D_2O moderator and reactor coolant and test reactors with very high temperature test loops (NU, Feb. '58, 65). All of these schemes assume the existence of an insulating medium that is radiation-resistant, has low nuclear absorption and can support large temperature gradients. W. R. Morgan, W. G. Baxter et al. (GE-ANP, Evendale, Ohio) have been able to show recently that these designer-invented materials really do exist.

In a survey of insulating materials the ANP group found that alumina-silica in felt form and "essentially pure" SiO_2 in batt form proved satisfactory for temperatures up to 1,800° F. In in-pile tests a temperature drop of 1,350° F was maintained across 0.2 in. of the materials without appreciable heat losses. For radiation doses of the order of 10^{13} n/cm²/sec for 300 hr, the SiO_2 showed no change in thermal conductivity while the alumina-silica thermal conductivity fell about 10% during the irradiation and recovered afterward. No changes were observed in the physical structure of the materials. Irradiation of samples at 1,650° F by a 9-Mev cyclotron beam to a dose of $\sim 5 \times 10^{16}$ deuterons/cm² also produced no detectable damage. Pile-oscillator experiments showed that the neutron-absorption cross section was low for both materials (about 10^{-2} cm²/gm).

Zircaloy vs Stainless: A Cost Comparison Taking account of savings in fuel inventory because of its lower neutron-absorption cross section, Zircaloy, even at current prices of $40–60/lb, is competitive with stainless steel for permanent parts of power reactors using fuel enriched up to 4% and for cladding natural and slightly enriched fuel. These are the conclusions of a study conducted by Manson Benedict, head of the Nuclear Engineering Dept. at M.I.T., for the Columbia-National Corp., producers of Zr sponge.

Designers of power reactors, e.g., Indian Point and Yankee Atomic Electric, have generally chosen stainless for cladding and structure. Columbia-National feels that Zircaloy may have been sold short.

To determine the relative economics of Zircaloy and stainless over the entire range of fuel enrichment, Benedict made calculations for five reactors: NPD (Canadian GE), Sodium-Graphite Reactor (Atomics International), Yankee Atomic Electric Reactor (Westinghouse), Merchant Ship Reactor (Babcock & Wilcox) and Vallecitos Boiling Water Reactor (GE).

Break-even prices of Zircaloy were computed for each reactor, i.e., the price at which the lower cost of uranium inventory is just balanced by the difference in cost between Zircaloy and stainless. The stainless price is taken as $5/lb (for close-tolerance items involved here). The calculated break-even prices ($/lb) are:

	% U^{235}	*Cladding*	*Permanent parts*
NPD	0.71	$104	$842
SGR	1.8	57	592
Yankee	2.6	51	—
MSR	3.64	44	141
VBWR	93	10	—

The large difference between cladding and permanent parts derives from the fact that new cladding is needed with each fuel change, whereas permanent parts are used for the life of the reactor. The present Zircaloy price ($40–60/lb) is well within range for permanent reactor parts. As cladding, Zircaloy would be advantageous for natural uranium (NPD), possible for the MSR fuel and unfeasible for highly enriched fuel.

The possibility of zirconium-water reaction is not believed to present a containment problem. Steps taken to contain a nuclear incident should be more than enough to contain such a reaction.

Others commenting on the Zircaloy-stainless picture have pointed up additional factors. A significant reduction in Zircaloy fabrication cost may be brought about by spin-casting, which is attracting wide attention.

Also, long-term operation of reactors using stainless may show up a radioactive-contamination problem. This could necessitate a switch to more expensive low-cobalt stainless, a further incentive for using Zircaloy.

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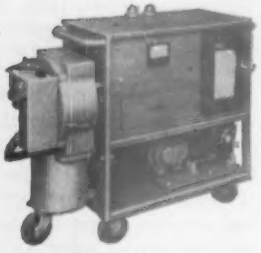

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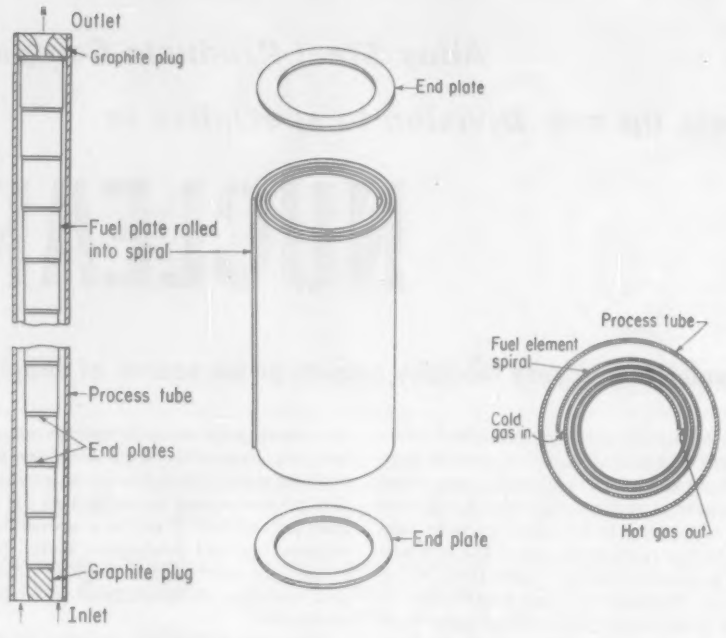

Spiral Fuel Element for Gas-Cooled Reactors

By R. C. DAHLBERG, *Knolls Atomic Power Laboratory,* Schenectady, N. Y.* and T. C. EVANS,† *Corps of Engineers, U. S. Army, Washington, D. C.*

The spiral fuel-element design described here emerged during a study of the feasibility of a D_2O-moderated, helium-cooled, natural-uranium power reactor. There are two main parts to the fuel-element assembly: the fuel spiral and the process tube (see figure). The spiral can best be described by outlining the method of fabrication as originally conceived. A thin sheet of uranium metal is clad on both sides with thin layers of, say, zirconium. Square zirconium wires are brazed to one side of the plate in the lengthwise direction. The wires are parallel and several inches apart. The resulting assembly is rolled up to form a spiral, the zirconium wires maintaining a constant separation of the plate surfaces.

The process tube serves to separate the fuel-element spiral and coolant from the moderator and, if necessary, to provide a pressure tube for the coolant. Fuel spirals are placed symmetrically inside the tube, and the top and bottom of the tube are closed off with graphite plugs. These plugs are orificed to provide an outer coolant channel between the fuel spiral and the process tube and an inner coolant channel enclosed by the fuel spiral. The spiral sections are joined together by metal end plates shaped like large washers.

In operation, cool gas enters the fuel element through the bottom plug and passes into the outer coolant channel. It then flows through the fuel spiral to the inner coolant channel and out of the element through the top plug. The square zirconium wires that maintain the spacing of the spiral annulus also minimize the drift of the gas in the axial direction. Coolant entering the outer end of the spiral must pass over

* Operated for AEC by the General Electric Co.

† On assignment with Army Reactors Branch, Division of Reactor Development, AEC, Washington, D. C.

the entire length of the fuel plate before it exits from the spiral.

The performance characteristics of this fuel element can be illustrated by presenting some of the results of the study of the D_2O-moderated, helium-cooled, natural-uranium power reactor of which this design formed a part. These results, given in the table, illustrate the application of the fuel element but in no way represent an optimum reactor design.

This fuel-element design is by no means devoid of defects. In the first place, it would probably be costly to fabricate, and, secondly, the pressure drop tends to be high. The seriousness of these defects depends on the ingenuity of the final design and might present no serious obstacle. A spiral fuel element of this type, however, has a number of unique characteristics.

• The moderator can be maintained at essentially the inlet temperature of the gas because only cool gas is in contact with the process tube. In a D_2O-

Characteristics of a Gas-Cooled Reactor Using Spiral Fuel Elements

Output	
Heat:	1,000 Mw
Electrical:	210 Mw
Core	
Configuration:	cylinder
Size:	20 ft dia × 20 ft
Fuel load:	75 tons
Power density:	13.5 Mw/ton
Burnup:	6,000 Mwd/ton
Fuel elements	
Type:	spiral
Number:	151
Enrichment:	natural
Spirals per element:	20
Spiral plate dimensions:	73 × 12 × 0.09 in.
Cladding:	zirconium
Spiral temp. (max):	1,150° F
Moderator	
Type:	heavy water
Inventory:	190 tons
Thermal utilization:	0.96
k_{eff} (max):	1.18
Leakage:	6%
Coolant	
Type:	helium
Flow:	3.78×10^6 lb/hr
Inlet temp.:	350° F
Outlet temp.:	1,000° F
Inlet pressure:	500 psia
Outlet pressure:	465 psia
Surface area per unit mass of fuel:	0.24 ft²/lb
Surface area per unit volume:	5.5 ft²/ft³
Heat-transfer film coefficient:	1,090 Btu/hr/ft²

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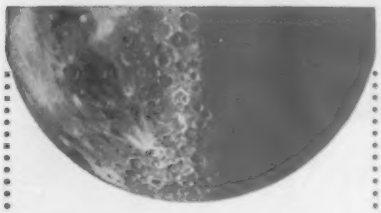

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moderated reactor these low D_2O temperatures mean low pressures and inexpensive pressure vessels. Furthermore, with the D_2O temperature relatively independent of the outlet gas temperature, medium- and high-temperature reactors seem feasible.

• The large surface area per unit mass of fuel and per unit volume leads to a power density that compares favorably with liquid-cooled reactors. Because of the large surface area per unit volume, it is possible to keep the maximum fuel plate temperature close to the outlet gas temperature.

• The length of the flow path that the coolant must follow in going through the fuel element is independent of the size of the reactor and is fixed only by the heat-transfer and fluid-flow conditions. Designing for the highest practical heat-transfer film coefficient, therefore, will lead to economic use of cladding and structural materials and will minimize the volume of coolant required.

• Because each small mass of coolant passing through a spiral receives practically all its heat at one axial position in a process tube, the performance of the element will depend sensitively on the axial and radial variation in power density. For optimum performance, process tubes will have to be orificed in the radial direction (by the top and bottom plugs) and fuel spirals will have to be orificed in the axial direction.

• The temperature variation across the fuel plate of the spiral is relatively small, the largest temperature drop occurring across the film. Because the fuel spiral can be made from a very long plate (several feet), it is possible to vary the total fuel load in the element over a wide range without seriously altering the heat-transfer properties.

• By varying the diameter of the fuel spiral with its axial position in the process tube (as shown in the figure), the maximum cold gas area is at the inlet end and the maximum hot gas area is at the outlet end—both features, of course, desirable.

* * *

The information reported in this paper was developed while the authors were in attendance at the Oak Ridge School of Reactor Technology. Associated with the authors in the study of this fuel element were: E. G. Beasley, T. K. De Boer, D. F. Molino, W. S. Rothwell and W. R. Slivka. R. A. Charpie acted as an advisor to the group.

Test Loop for Determining Burnout Heat Flux

By W. MILICH and E. C. KING
MSA Research Corp., Callery, Pennsylvania

The versatility of an experimental two-fluid test loop (Fig. 1), in which NaK is the heating medium and some other fluid the one in question, enables us to study the maximum nucleate boiling point, or burnout heat flux, of any fluid as a function of pressure, temperature and velocity and to study film boiling beyond the burnout region.

This loop is presently being used in the study of film-boiling coefficients for high-pressure water at various temperatures and velocities. The study of film boiling in a single-fluid system is inadvisable because the test apparatus would probably fail at burnout. In the two-fluid system, the pipe-wall temperature cannot exceed the bulk NaK temperature, thus preventing tube failure. Also, higher heat fluxes can be obtained using the liquid metal, and one is not concerned with the problem of elevated vapor pressures at the temperatures, as high as 1,400–1,500° F, used in this experiment.

Because organic fluids are being considered as coolant and moderator, information about the burnout heat flux is needed to permit adequate reactor design. Burnout is the point at which film blanketing of a heat-transfer surface first occurs. Film blanketing results in a drop in the film heat-transfer coefficient that, in turn, could result in overheating and possible failure of the surface in question.

The heart of the loop is a double-tube heat exchanger (Fig. 1). NaK flowing down the annulus between two concentric tubes heats the fluid under study

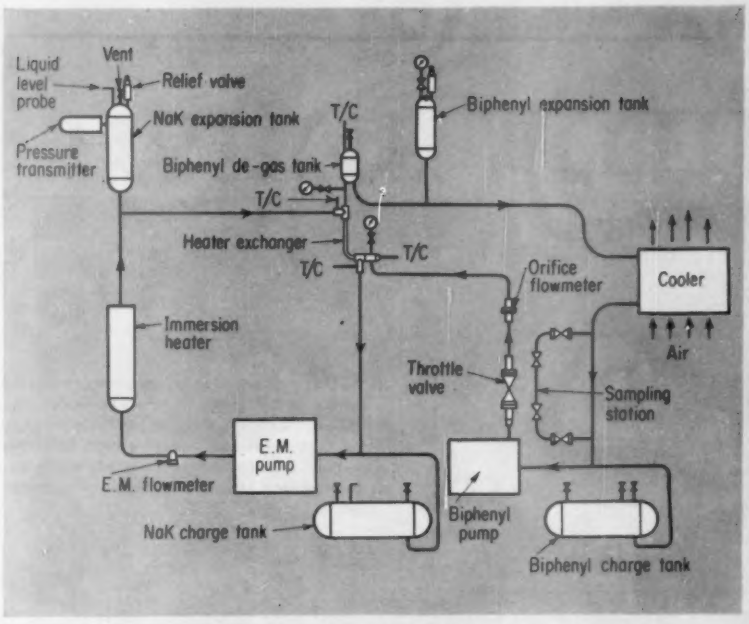

FIG. 1. Two-fluid test loop uses immersion heater to heat NaK, which then heats fluid under investigation as it flows through special heat exchanger

as the latter flows upward in the inner tube. The heat exchanger is "L" shaped to provide for differential expansion between shell and tube.

Discussion of Results

Figure 2 shows the result of tests made with isopropyl biphenyl flowing

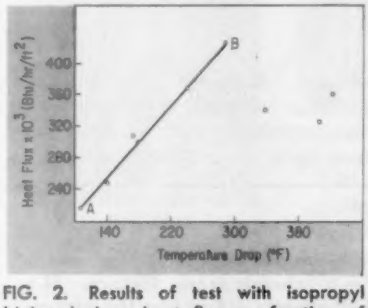

FIG. 2. Results of test with isopropyl biphenyl show heat flux as function of temperature drop through film. Break in curve at point *B* represents onset of film boiling

at a velocity of 10 ft/sec (7,400 lb/hr/ft²), a fixed heat-exchanger outlet temperature of 600° F and a system pressure of 300 psig.

Because there is no break in the curve between points *A* and *B*, we can assume that the biphenyl reached the nucleate boiling region. At point *B* the heat flux reached a maximum of approximately 429,000 Btu/hr/ft². This peak represents the maximum nucleate boiling point. The data were erratic beyond this point because of unstable film boiling and coking in the heat-exchanger tube. The coking resulted from thermal decomposition of the biphenyl at the elevated temperatures.

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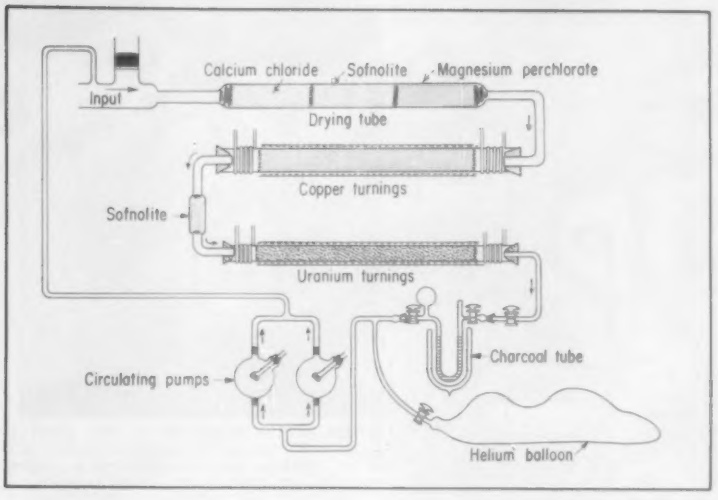

FIG. 1. Apparatus for preliminary purification of off-gases from uranium-fuel dissolver. Calcium chloride and magnesium perchlorate remove water vapor, Sofnolite removes CO_2, copper removes most impurities and uranium removes nitrogenous gases

Preparation of Xenon-133 Radiography Sources from Spent Fuel

By E. J. WILSON, H. P. DIBBS,*
S. RICHARDS† and J. D. EAKINS
Atomic Energy Research Establishment
Harwell, Didcot, Berkshire
England

It is unlikely that radioisotopes will compete with X-ray tubes in attaining the precise exposures required in clinical radiography. However, thulium-170 and xenon-133, which emit gamma rays of 84 and 81 kev, respectively, are proving of value for specific applications (*1–3*) where conventional X-ray machines are inconvenient or unapplicable. For example, in dental radiography highly defined radiographs can be attained by inserting a small radiographic source into the mouth so that only one side of the skull is exposed to the radiation.

Whereas Tm^{170} is made by irradiating thulium oxide in the pile and consequently resulting in a product of low specific activity, xenon-133 is a fission-product gas of quite high specific activity. As the strength of a thulium source is increased, the proportion of brehmsstrahlung, with an energy spectrum up to about 1 Mev, increases so

* PRESENT ADDRESS: Commercial Products Div., Atomic Energy of Canada Ltd., Ottawa, Canada.
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Krypton–85 Sources

Krypton-85 is a highly useful tracer—powerful beta (0.68 Mev max.), 10.4-yr half-life, inert gas. Inertness is a valuable safety feature. If a container breaks and releases krypton, it rapidly diffuses in the atmosphere, becoming diluted to negligible levels. It cannot adhere to surfaces as a contaminant or enter the body metabolism as a biological threat.

E. J. Wilson et al. recently described (AERE I/R 2216, 1957) krypton-85 production at Harwell by a procedure used in conjunction with the xenon-133 production method described in this article. Highly purified fission-product krypton is obtained with a specific activity of 125 curie/liter.

Preliminary purification is accomplished in the apparatus of Fig. 1. The inert gases, krypton, argon and xenon, are passed from the charcoal trap to a bulb and then absorbed in a charcoal chromatographic column. As the column warms up, argon comes off first and then krypton, which is collected in traps. Xenon remains in the column. Carrier helium is removed by pumping before krypton is removed from the collection traps.

Krypton is being used increasingly as a gaging source (NU, March '57, p. 66) and as a gaseous tracer (NU, March '58, p. 62). It is also useful as a radiation source. A few millicuries in a thin-walled aluminum tube is an effective static eliminator. The safety of inertness is an advantage over alpha emitters that present a serious contamination problem if the protective coating is damaged. In gas-filled electron tubes, krypton produces ionization to promote uniformity in ignition characteristics.

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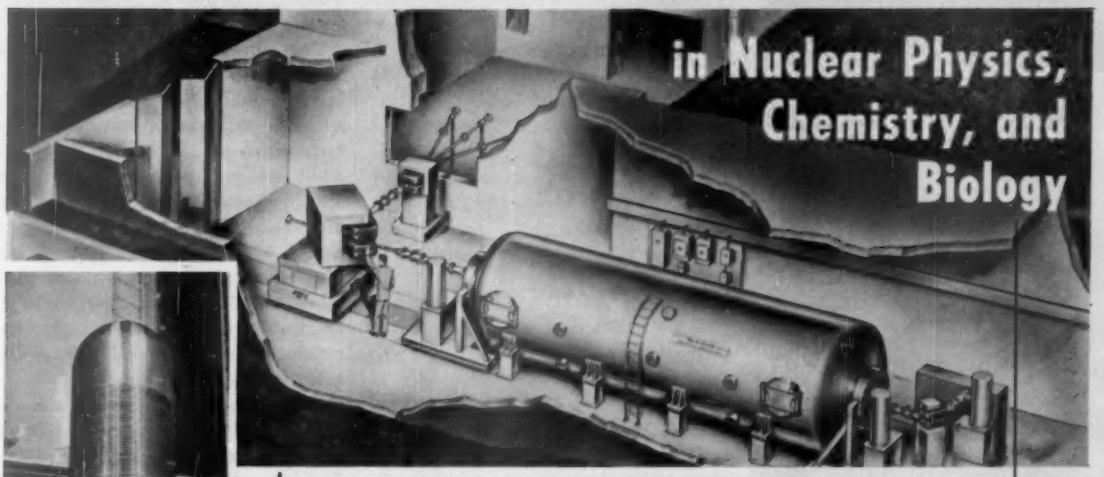

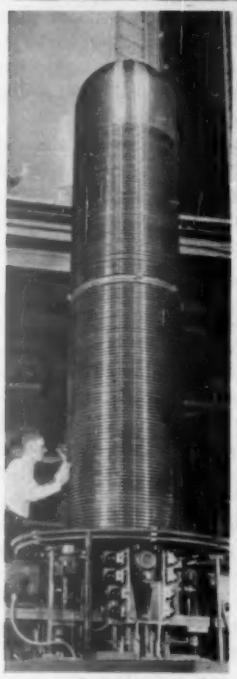

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This article starts on page 110

much that in addition to deteriorating the definition of the radiograph, increased shielding is required for protection against the more energetic radiation. Brehmsstrahlung emission from xenon-133 sources, on the other hand, is insignificant.

The chief disadvantage of xenon-133 is the short half-life of 5.27 days. Our present method of preparation is not economical for the occasional experiment at the moment, but with higher-flux reactors becoming available more intense sources will probably be obtainable at a much reduced cost.

Preliminary Treatment

A 2.3-kg uranium slug irradiated at a flux of 10^{12} n/cm²/sec for 6 days will produce 28 curies xenon-133 and for 13 days, 41 curies. After irradiation, the slug is stripped of its aluminum sheath and inserted into a fumeless dissolving plant originally designed for iodine-131 production, but temporarily modified for this purpose (*4*). The plant consists of a stainless-steel, steam-heated dissolver of 70-liter capacity connected to a conventional dissolver and receiver. About 12 liter of 10*N* HNO_3 at 104° C is used for dissolving the slug, with oxygen admitted to regenerate nitric acid from nitrous fumes.

The gases evolved from the solution are carried by a slight excess of oxygen through a preliminary purification plant, shown in Fig. 1. Here, the stream of dissolver off-gases joins a continuous stream of helium slowly circulated over the purification train by two small pumps. Each pump is fitted with two sintered glass disks covered with a pool of mercury to act as nonreturn valves and a nichrome-tape filament heated intermittently by a Simmerstat. During the heating cycle, gas is forced through the upper valve while, during the cooling cycle, gas enters the bulb through the lower valve. The 1 liter/hr pumping rate is adequate for the purpose (*5*).

The purification train consists of drying tubes, a copper furnace maintained at 600° C to remove oxygen and a furnace packed with uranium turnings maintained at 850–900° C to remove additional impurities such as nitrogen and hydrocarbons. The inert gases are condensed in a liquid-nitrogen-cooled charcoal trap. Because the dissolution of uranium is nonuniform, a helium balloon is incorporated in the apparatus to maintain the system pressure at atmospheric during sudden surges of gases from the dissolver.

About 8 hr are required for this part of the process. Final traces of xenon are removed from the dissolver by flushing with helium gas admitted below the surface of the liquid.

Xenon Purification

The preliminary purification apparatus, unlike the dissolver (which is enclosed within a thick concrete cell), is unshielded, apart from a ½-in-thick lead container enclosing the charcoal trap and liquid-nitrogen Dewar. On completion of the dissolution, the trap is removed and attached to a high-vacuum apparatus shielded by ¼-in. lead (Fig. 2). This apparatus was designed for remote-control operation. To avoid such conventional devices as mercury cut-offs and stopcocks operated through lead walls, electrically operated solenoid valves

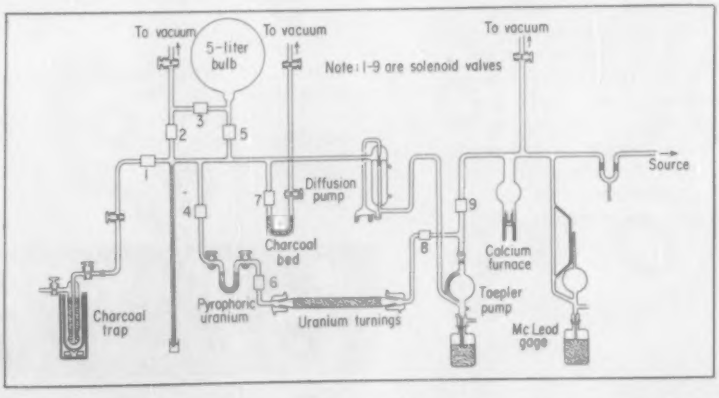


FIG. 2. Xenon-133 purification apparatus. Charcoal trap contains gases collected in preliminary-purification apparatus (Fig. 1). Trap shown here is later modification of that shown in Fig. 1

are used. These consist essentially of spring-loaded, soft-iron plungers with neoprene seatings. With suitable modification, they can maintain a 76-cm-Hg difference across the seating, although this was not essential in the present system where pressure differences rarely exceeded 10 cm of mercury.

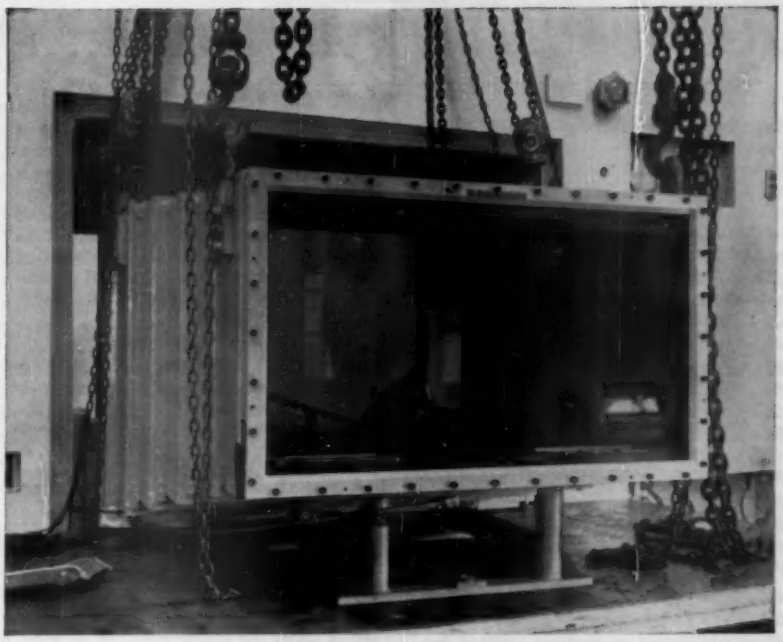
Residual helium and less strongly adsorbed gases are first pumped out of the charcoal trap while still under liquid N_2. The N_2 is then replaced by boiling water to drive off all absorbed gases, which are transferred to a purification train by an automatic Toepler pump. They are then circulated over uranium turnings, maintained at 900° C to remove all gaseous impurities except the inert gases and hydrogen, and pyrophoric uranium at room temperature. Any hydrogeneous gaseous impurities are decomposed to hydrogen by the uranium turnings, and the hydrogen is taken out by the pyrophoric uranium. This leaves only the inert gases argon, krypton and xenon, the krypton volume being negligible compared with the others.

Separation of argon from xenon is accomplished by adsorbing the gases on charcoal with liquid nitrogen, and then replacing this refrigerant by methylated spirits cooled with liquid nitrogen to −90° C. On opening the charcoal bed to a 5-liter bulb, argon is desorbed and can be pumped away. Performing this operation two or three times rids the charcoal of almost all the argon leaving the xenon adsorbed.

Finally the xenon is transferred by Toepler pump to the source section of the apparatus, where it can be adsorbed on a small plug of fine-mesh activated charcoal embedded in a hard-glass capillary tube and the latter sealed off. The calcium furnace may be used for removing trace impurities other than inert gases.

Since the theoretical specific activity of xenon-133 is about 200 curies/cm³ and the adsorption of xenon on charcoal at room temperature is about 70 cm³ per gram of charcoal, quite intense sources can be achieved using a plug of charcoal, 1-mm diameter by 5-mm length. Specific activities have been achieved of the order of 100 curies/cm³.

More favorable point sources could be obtained by reducing the size of the charcoal plug, which would mean an increase of the internal pressure of gas. Experiments with the capillary tubing used indicate that the glass can withstand at least 20 atmospheres pressure. In fact bursting strengths for soda-



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Since we started in business, one of our important activities has been conducting site surveys for operators of nuclear reactors. These studies are undertaken prior to start-up to determine the level of "background" radioactivity in the area surrounding the reactor.

This then provides a basis for measuring any increase in radioactivity after the reactor is in operation. Environmental radioactivity studies are required. Such studies should also be made on a continuing basis not only for safety's sake but to provide "third party" legal protection against lawsuits and insurance claims.

In conducting a site survey, NSEC takes samples from the surrounding area. These may be soil, ground water, plants, animals, fish, rainwater, dust, sewage or other materials. We consider carefully the nature of the facility, the terrain, direction of air movement, and surface and ground water flow. The samples are processed and analyzed in our labs. We are then able to establish the radioactivity level, the kinds of isotopes producing it, and the possible sources of these isotopes.

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Recently, in the largest radioactive tracer study ever conducted in the United States, NSEC successfully traced the dispersion of sewage effluent flowing into ocean waters. Our study helped the City of Los Angeles in planning expansion of its sewage system. First we injected the isotope scandium-46 into sewage about to be released into Santa Monica Bay. This enabled us to measure the pattern of sewage diffusion and its dilution in sea water to one part in ten thousand.

Write for a copy of "Radioactive Tracer Study of Sewage Field in Santa Monica Bay" by Dr. Ralph L. Ely, Jr. (He's our Vice President and Technical Director.) Or ask about our forthcoming study for the Republic of Venezuela, in which we will investigate littoral drift, using radioactive sand, to determine the feasibility of a certain harbor location.

RADIATION SICKNESS

It's common knowledge that excessive radiation produces harmful effects in human beings, ranging from mild nausea or skin burns to cancer and death. Recent experiments under the direction of Dr. A. Edelmann, Manager of our Department of Biology and Medicine, have indicated that radiation can also produce a toxic factor which appears in the blood. Analysis of the blood of rats subjected to X-rays under varying conditions not only indicates that a toxic element is produced but that it may be transferred by injection from one animal to another.

When and if this toxic substance is identified, it may be possible to devise an antitoxin to alleviate some of the effects of atomic radiation. *Medical and pharmaceutical applications of controlled radioactivity open up entirely new means of studying existing problems. Contact Dr. Edelmann about your problem.*

DETERMINATION OF BORON IN SILICON

A major problem plaguing the electronics industry is achieving ultra-pure silicon for transistors. Current methods are slow and costly, but effective. Nevertheless, boron still remains as a damaging impurity even in minute quantities of only a few parts per billion. Ordinary chemical methods cannot detect the presence of boron in such small concentrations.

However, NSEC scientists are now perfecting a process by which the boron is transmuted into radioactive carbon-11 and subsequently measured by its radioactivity.

This new method of analysis will be helpful in the quality control of silicon during production. *Once a routine method is established it will be offered on a commercial basis. Interested? Drop us a letter.*

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This article starts on page 110

FIG. 3. Radiograph of hand obtained with xenon-133

glass capillaries are quoted at 560–570 atmospheres (*6*). However, because of insufficient knowledge of the radiation damage to such capillaries, it is not advisable to operate at higher pressures than one atmosphere.

Estimating Xenon Activity

Xenon activity is estimated either by using an argon-filled re-entrant TPA ionization chamber or with the source in a standard jig in conjunction with a 1005 β-γ monitor, about 1 meter or more from the source. Both these are calibrated by correlating the xenon activity, estimated after suitable dilution by gas counting, with the ionization current.

Dose-rate measurements performed at the same time, although differing markedly from point-source geometry, indicated a K factor for Xe^{133} of about 500 mr/hr/mc in satisfactory agreement with the theoretical value based on recent decay schemes (*7*, *8*).

A typical radiograph is shown in Fig. 3.

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APPLIED RADIATION

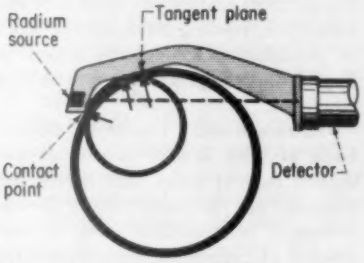
Gages + Computers → Sophistication It has been estimated that the market for radionuclide gages is only 10% saturated. Even so, the industry is finding new potential so fast that the market may be expanding faster than the filling of it. New kinds of gages and new ways to use old ones are growing as fast as production facilities for making standard models.

Machine-controlling gages for instance. They control density or weight within specified tolerances, but that's only the beginning. If you watch the variation within these tolerances, you have an indication of which producing machine needs maintenance next and when it needs it.

That isn't all; information can be more specific. Radioactive gaging had hardly got settled into its job on production lines before the old hands began to develop a "feel" for some of the extra information in their data. "If they watched the trace for a while," reports one gage designer, "they could turn around and say, 'That left upper fenestron over there must have a worn tooth.'" *This* kind of period in the trace on the chart meant that *that* particular belt was slipping, and so on.

Now the gage builders are making art into science and devising computers that will appreciate all of this available information. Simplest of all is a counter that tells how many rejects are over tolerance and how many are under. It's almost too simple, but a multitude of new gage users need the information it provides. More sophisticated gaging computers are on the drawing boards.

Paper gaging, too, is becoming more refined. Old-fashioned methods (those of a few months ago) control either the thickness at a point or some kind of an average across the sheet. But more data are available. Why waste any?



Pipewall gage reading depends on wall thickness but not radius

In paper making several outlets dump their pulp outputs onto a moving screen. This pulp travels along through the manufacturing process until it is turned into paper. The sophisticated gage designer will try to control each nozzle and achieve a maximum in product uniformity. He measures the profile, runs the data through a computer, and corrects the flow of each outlet to overcome deficiencies.

Pipe walls are subjects for radiation gaging, too. Their thickness is a measure of the corrosion and wear going on inside. You might think that radius of curvature would be a major problem and that almost any gage would have to be designed for a particular diameter or calibrated for each kind it is applied to. But it turns out that a point of contact and a tangent plane determine a chord that makes separate calibrations unnecessary. For the same wall thickness this chord contains a constant amount of material no matter what the radius of curvature. (Try it!)

Industrial Nucleonics' pipewall gage (see figure) is designed to take advantage of this situation. It measures all of the pipes in most process equipment—pipes with diameters of 2–5 in. The source is 0.2 mg (0.2 mc) of radium in radium sulfate, and the detector is a G-M tube in the handle.

Neutron gaging has exciting possibilities that are still in the dreamer stage. Neutrons are absorbed and scattered, and they produce prompt and delayed gamma photons. Moreover there now are new ways to produce them in significant numbers without going to the bulkiness of a graphite pile. Why not run the sample through a small reactor or a pulse of neutrons from a discharge tube and then observe the neutrons and gammas that come from it? With a simple computer and a few meters, it might be possible to find all of the things you need to know. Automatic equipment would count and record transmitted and scattered neutrons and prompt gammas as neutrons struck the sample. At later points in the production, delayed gammas would be counted. A computer would combine this information to find size, shape, and composition.

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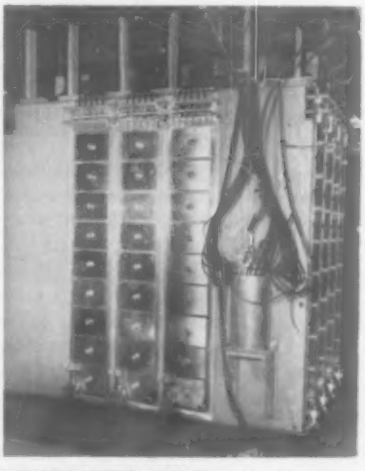
Shock-wave experiments. In these experiments* a high-temperature plasma is generated by striking a high-current discharge between two electrodes located in the cross piece of a "T"-shaped tube about 1 in. in diameter. Peak discharge currents are typically 200,000 amp reached in 3 μsec. The lead to one of the electrodes is placed parallel to the current path between the electrodes. The repulsion between the current in the lead and the current in the discharge drives the ionized gas of the discharge along the perpendicular "riser" of the "T." It is driven at such velocities (~100,000 m/sec) that a shock wave is formed that further heats and ionizes the hitherto neutral gas in its path. To insulate this shock wave from the walls of the tube, a current pulse from a second capacitor bank is sent through a coil that encircles the tube. The resultant magnetic field, parallel to the tube axis, exerts a magnetic pressure on the plasma pushing it away from the walls.



NEW CAPACITOR BANK at Naval Research Laboratory consists of 99 parallel capacitors in 11 columns of 9 capacitors each

Thus one has a means for imparting energy to an ionized gas and insulating it from the surrounding walls—the necessary ingredients for a thermonuclear reactor. Of course means must be found to keep the fast-moving plasma from hitting the far end of the tube, but, reading between the lines of published NRL reports makes it appear that the problem is regarded as tractable.

The new bank. The new capacitor bank at NRL is used to provide the second current pulse that drives the plasma from the walls. Since the inductance of the field coils is low (~0.01 μh), stringent requirements are placed on the capacitor banks if the external inductance is to be low compared with that of the coil as required for efficient energy transfer. This isn't easy since the capacitor bank consists of 99 capacitors in 11 columns of 9 capacitors each and stores 285,000 joules (1,430 μf at 20 kv). Nevertheless, the inductance of the external circuit is held to 0.003 μh, and the bank has a short-circuit-current capability in the neighborhood of 15-million amp with a rise time of 0.3 μsec. The trick lies in such construction details as connecting the capacitors with "transmission lines" consisting of copper sheets 14 in. wide separated by 0.028 in. of Mylar.

Each column is switched individually. The switches can be seen at the top of each column in the figure and are simply gaps in one sheet of the transmission lines. The current flowing across the gap is driven away from the insulation by magnetic fields generated by the current in the bottom plate of the transmission line. This prevents burning of the insulation by the enormous switched currents. The switches in turn are triggered by 5 spark gaps each connected in parallel by coaxial cable. Trigger capacitor and the 55 associated cables are seen to the right in the figure. The current from the 11 columns feeds into parallel copper sheets, each 8 ft wide and 10 ft long on the top of the bank leading to the shock tube on the floor above. Currents of 7–10-million amperes can be fed into the coil, depending on its size. With currents of this magnitude it is possible to generate half-megagauss magnetic fields over an appreciable volume of experimental apparatus.

* A. C. Kolb, *Phys. Rev.* **107**, 1197 (1957).

Physik und Technik der Atomreaktoren

By FERDINAND CAP (Springer-Verlag, Vienna, 1957, xxix + 487 pages, about $15.00).

Reviewed by HENRY HAUSNER, Consulting Engineer, New York, N. Y.

This first book in German on the physics and technology of nuclear reactors is well written by a professor of theoretical physics at the University of Innsbruch, Austria. He obtained his practical experience at the nuclear research centers in France and Scandinavia.

More than half of the book is devoted to reactor physics, and this part is written with a thoroughness generally attributed to German scientists. It should be mentioned that the book contains 100 illustrations, more than 1,300 equations—including the derivation of most of them—and 128 tables with data from the literature up to the end of 1956. This reviewer was especially impressed with the chapters on the kinetic neutron theory and on the critical volume.

The second part of the book is devoted to engineering and economic problems, which are as well treated as is possible in less than 200 pages. The important problems of reactor materials are rather sketchily treated, being covered in 50 pages. The economic problems, however, are discussed extensively, although some tables, such as the cost data of atomic power in various countries, are somewhat erroneous and misleading. Each chapter of the book contains a series of well selected problems for nuclear engineering students, which should be worthwhile translating for teaching purposes in our schools.

In the *Introduction*, the author mentions that there exists no standardized German nuclear terminology, and that he has therefore created his own terminology, which actually represents a translation of the English terms. In the extensive subject index, however, he has added to many of his own German terms the corresponding item in the English language according to the glossary recently accepted by the American Standards Association, which facilitates the study of this valuable book for the English-speaking reader.

It is strongly recommended that this book be translated into English.

BOOKS RECEIVED

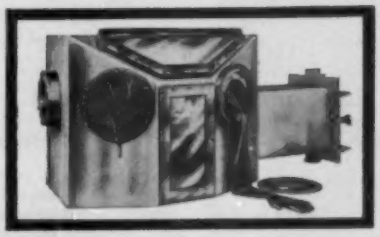
System Engineering, by Harry H. Goode and Robert E. Machol (McGraw-Hill Book Co., New York, 1957, xii + 551 pages, $10.00). This book is subtitled "An Introduction to the Design of Large-Scale Systems." The systems are those that man has developed to cope with the increasing complexity of our society; an example is the electronic-digital-computer system. For the most part, this book can be read with a background of elementary calculus. Sections of the book are concerned with probability, exterior- and interior-system design and computers.

Free Radicals in Solution, by Cheves Walling (John Wiley & Sons, New York, 1957, xii + 631 pages, $14.50). This book is written as a comprehensive survey of organic free radicals in solution. The author bases his discussion on his interest in reaction kinetics and radical chain processes. The first part of the book develops the theory using vinyl polymerization for illustrative purposes. The later part of the book gives applications to double bonds, halogen substitutions and autoxidation.

Handbook of Chemistry and Physics, 39th ed., (Chemical Rubber Publishing Co., Cleveland, 1957, xxii + 3213 pages, $12.00). This most useful reference for the experimentalist has in this edition, as in previous ones, increased its value by revision and addition. New tables include nuclear spin and moments, nuclear magnetic resonance, superconductivity, electron mass and energy, and dielectric constants of liquids and gases. The isotope table has been revised and information added on the transuranium elements.

Principles of the Properties of Materials, by J. P. Frankel (McGraw-Hill Book Co., New York, 1957, xiv + 228 pages, $6.00). This text deviates from the traditional pattern by emphasizing properties rather than materials. It is the author's contention that the student can then apply his knowledge to new materials. He further contends that the current technological bottlenecks created by materials problems will be broken by those with a thorough knowledge of properties.

for work in a controlled atmosphere



BLICKMAN
VACUUM DRY BOX

Designed for safe handling of radio-isotopes, reactor fuel containing Plutonium or U233 and other hazardous substances. With air-lock, it can be sealed to create a vacuum. Fabricated of stainless steel plate—34" long x 26" high x 24" wide at base. Air-lock measures 18" x 12". Send for Technical Bulletin A-2.

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Originally designed and developed for the AEC, this Fume Hood assures maximum safety in the handling of radioactive materials and radioactive isotopes. Sturdy 14-gauge stainless steel, round corner construction provides long life...easy cleaning and decontamination. Send for Technical Bulletin E-3. S. Blickman, Inc., 7904 Gregory Avenue, Weehawken, N. J.

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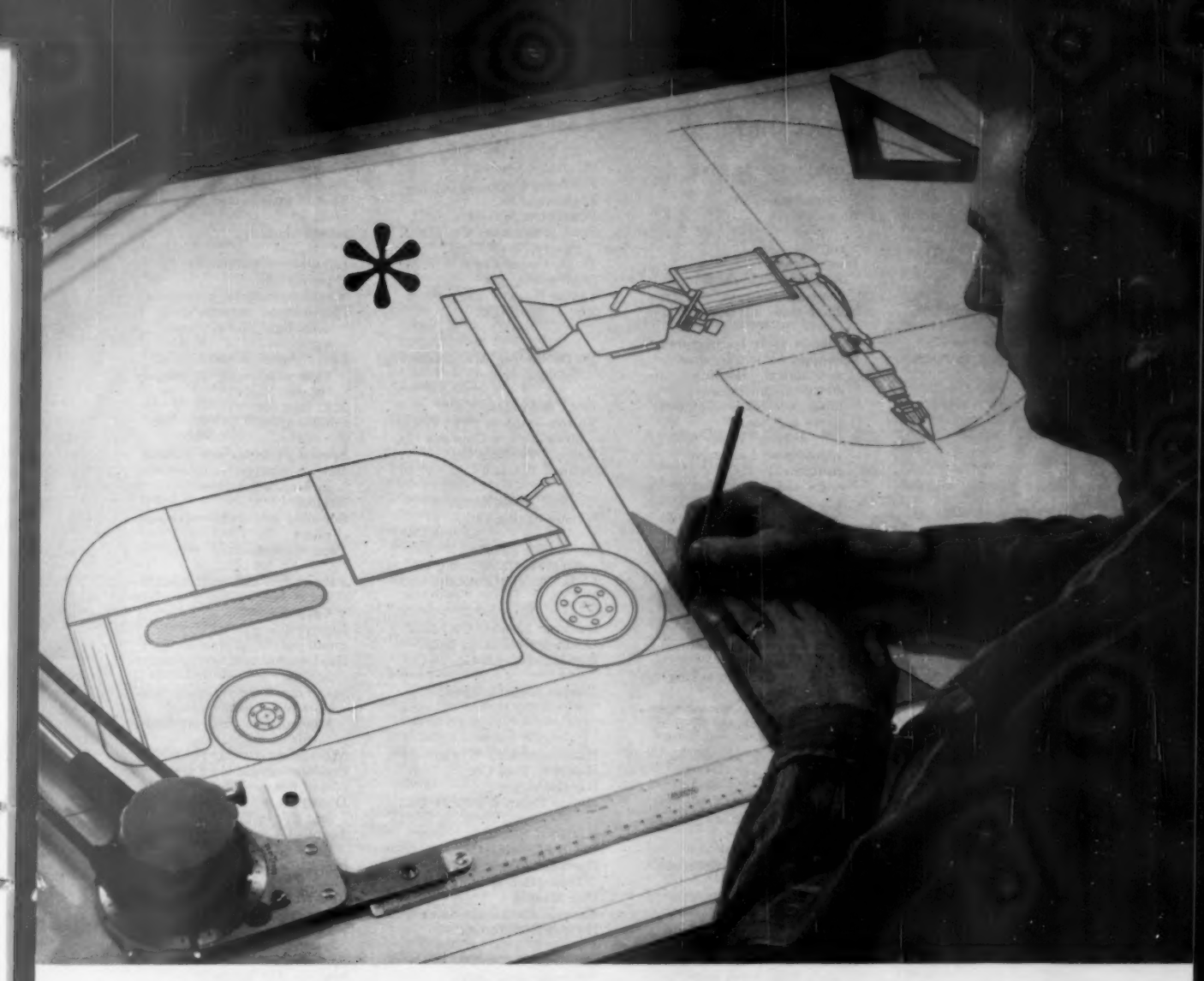
PRODUCTS AND MATERIALS

From May 1954 to October 1957 at least 465 different companies supplied approximately $55-million worth of products, materials and services for the Shippingport Atomic Power Station. To acquaint our readers with the range of goods and services involved in this first full-scale commercial nuclear-power plant, (see Special Report, p. 53) NUCLEONICS presents the following partial list compiled by Westinghouse Electric Corp., prinicpal contractor for the nuclear portion of the plant, which will be operated by Duquesne Light Co.

Suppliers to Shippingport

Supplier	Contribution to PWR
Air Reduction Sales	Seal-weld machine, weldrod, miscellaneous welding
Alco Products, Inc.	Regenerative and nonregenerative heat exchangers
Aldrich Pump Co.	Hydrostatic-test pump
Allegheny Ludlum Steel Corp.	Heat-exchanger tubing
Allen-Bradley Co.	Electrical components
Allen Gauge and Tool Co.	Blanket-disassembly tools, gages
Allis-Chalmers Mfg. Co.	Main coolant pumps, a-c–d-c M G set
Allegheny Industrial Electrical Co.	Electrical contractor
Alloy Manufacturing Co., Inc.	Demineralizer vessel, ion exchangers, blanket-disassembly tools, weldments, analytical trains; fabricated and welded bottom support plate, core-cage barrel, core-holddown barrel
Alloy Welding Co.	Performed critical welding operations for many major valve suppliers; special cladding
Aloe Scientific	Scientific equipment
Aluminum Co. of America	Aluminum tubing for core-handling tools, stampings for mechanism housings
American Bridge Co.	Canal gates, structural steel
American Car and Foundry	Fabricated reactor-vessel filter under subcontract to Cumo Engineering Corp.
American Instrument Co., Inc.	Laboratory instruments
American Standard	Small manual globe and needle valves, primary plant instrumentation auxiliary instrument panel
American Steel Foundry	Fabricated Inconel-X springs for primary relief valves
American Welding & Manufacturing Co.	Control-rod shrouds
Amphenol Electronic Corp.	Electronic panel connectors
Anchor Drawing Co.	Centerless ground Inconel-X bars
Anchor Packing Co.	Gasket material
Andale Co.	Small valves and strainers
Anton Electronics Laboratories	Cart-mounted air-monitor units, air-particle detectors
Apolla Steel Co.	Core-pit stand
Arcadia Synthetic Products Div., Western Felt Works	O-rings and gaskets
Arch Machinery	Industrial tools and equipment
Arde Associates	Thermal and hydraulic studies
Armco Steel	17-4 PH stainless steel
Armour Research Foundation	Research on UO_2 properties, fission-product-removal studies, thermal-agitator-distortion study
Arnold Greene Co.	X-rayed castings for valve suppliers
Associated Valve & Engineering Co.	Small valves
Atkins & Merrill, Inc.	Design-study models
Atwood & Morrill Co.	6-in. motor-operated stop valves, 6-in. venturi gate valves, small valves
Auburn Atomic, Inc.	Drafting services
Autoclave Engineering	Small valves
Automatic Switch Co.	Small valves
Babcock & Wilcox Co.	Steam generators, main coolant piping, tube-plugging pins
Bailey Meter Co.	Main instrument console, D P cells, resistance thermometers
Baird-Atomic, Inc.	Laboratory instruments
Bakelite Co.	Insulating material
Baker & Co., Inc.	Cadmium tubing
Baldwin-Lima-Hamilton Corp.	Motor cranes, use of betatron facilities
Barnes, Gibson & Raymond	Springs
Barth Corp.	Final machining of locking collars and latch rings
Barton Instrument Co.	D P cells, flow switches
Basic Engineers, Inc.	Engineering and drafting services
Battelle Memorial Institute	Development of uranium-alloy fuel materials and elements, measurement of U-base alloys and effect of water composition on corrosion, development of UO_2 cermets, high-strength-materials evaluation
John Bean Div., Food Machinery & Chem. Corp.	Charging pumps
Bearing Distributors, Inc.	Bearings, gaskets
A. O. Beckman, Inc.	Gas analysis equipment
Beckman Instrument Co.	Counting-room and air-sampler equipment, beta-gamma detector indicator channel
Bendix Aviation Corp.	Control-rod drive mechanisms
Berger Engineering Co.	Pipe-cutting and weld-preparation machine
Bethlehem Steel Co.	Reactor-vessel-flange forgings
James G. Biddle Co.	Instruments
Bishop and Babcock Co.	Flexible connectors
Black, Sivalls & Bryson, Inc.	Spare parts for pumps and valves
S. Blickman, Inc.	Fabrications
E. W. Bliss	Large machining
Boder Scientific Co.	Instruments
Bonney Floyd Co.	Supplied cast parts for various subcontractors
Bristol Co.	Pressure transmitters and receivers
Brosky X-Ray Laboratory	X-ray evaluation of head penetration housings, pump and valve castings
Brown Instrument Div., Minneapolis-Honeywell Regulator Co.	Sampling-room panel, core-instrumentation panel, failed element detection and location system panel, chart recorders, small valves
Builders-Providence, Inc.	Venturi flowmeter orifices
Burrell Corp.	Laboratory equipment
Blow-Knox Co.	Waste-disposal piping system, air locks
Cadillac Plastic & Chem. Co.	Plastics
Cambridge Instrument Co.	Ph cells and recorder
Camden Copper	Vent-gas, decay-gas and exhaust filters, standing waste and drains
Cameradio Co.	Electronic parts
Canton Drop Forge & Manufacturing Co.	Cruciform extrusions
Canton Tool Mfg. Co.	Refueling and instrument-port seal-weld cutting machine
Carbide Specialty Co.	Machined parts
Carborundum Co.	Grinding wheels
G. O. Carlson, Co.	Stainless-steel plates
Carpenter Steel Co.	Stainless-steel bars and rods
Cello Print	Polyethylene sheet
Century Electric Co.	Valve motors



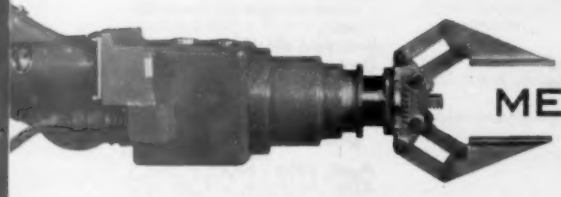
*Answers to your future handling problems may already be on our drawing boards

Perhaps this is one of them. This unmanned, remotely controlled mobile handling unit is among the new designs being developed at General Mills. Manned mobile units with shielded cabs also are in the works.

Mobile manipulators and other new concepts in handling "hot" materials are not the only results from the continuing development effort in our Nuclear Equipment Department. Development engineers have made a succession of improvements in the General Mills Mechanical Arm and its accessories. Continual improvement has kept this manipulator a standard item in the industry.

Engineers with nearly a decade of experience in the atomic field also are available for consultation on your specific problems. Use of our specialized know-how in the early planning stages of your installation could save you time and money.

For more information on our complete nuclear handling service, or for details on the Mechanical Arm, or any of its accessories, write, wire or phone: Nuclear Equipment Department, Mechanical Division of General Mills, 1620 Central Avenue, Minneapolis 13, Minnesota. Phone: STerling 9-8811.



MECHANICAL DIVISION

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General Mills

European Sales Representatives:
Leybold-Hochvakuum Anlagen GmbH, Cologne, West Germany

Suppliers to Shippingport (Cont.)

Supplier	Contribution to PWR
Chandler Boyd	Fittings, pipe
Chapman Valve Manufacturing Co.	Small valves
Chempump Corp.	Pumps
Cherry-Burrell Corp.	Instruments
Chicago Steel Tank	Cooling-water expansion tank, vent-gas surge drum
Cleveland Hard Facing	Stellite-clad various components
Cleveland Tool & Die Co.	Precision tools and fixtures
Cleveland Tooling Industries, Inc.	Seal-weld cutting machine, mechanism housings, instrument-port closure plugs, precision-machined parts and tools
Colonial Supply Co.	Small valves, pipe, fittings; grinding and abrasive equipment
Combustion Engineering, Inc.	Design and fabrication of reactor vessel, thermal shields, flow guide, flash and blowoff tanks
Commercial Plastics & Supply Corp.	Plastics
Conco Crane	1-ton, 15-ton and 20-ton cranes
Connellsville Mfg. & Mine Supply Co.	Base-plate assembly
Consolidated Electrodynamic Corp.	Pressure transducers, mass spectrometers
Corning Glass Works	Studied thermal cracking of UO_2
Crane Co.	Primary 18-in. motor-operated stop valves, ½-8-in. valves
Crosby Gage & Valve Co.	Primary relief valves, small valves
Crucible Steel Company of America	Stainless steel
Crump, Inc.	Building construction
Crystal X Corp.	Polyethylene sheet
Cuno Engineering Corp.	Reactor-vessel filter
Cushing and Nevell, Inc.	Reactor-component instruction manual
Cutler-Hammer, Inc.	480-v motor-control center
Daniel Orifice Co.	Orifices
Daven Co.	Switches
Deming Co.	Centrifugal fill pump
Diversey Engineering Co.	Control rods, spline shafts, latch nuts, latch seats, lock sleeves
Downington Iron Works	Drain receiving tank
Dravo Corp.	Construction contractor; ready-mixed concrete
Dow Corning Corp.	Plastics
Duer Spring Co.	Supplied springs to valve suppliers; tool springs
Allen B. Dumont Laboratories, Inc.	Instrumentation
Dyna Empire Corp.	Pump-noise monitor
Edward Valves, Inc.	Primary 18-in. check valves, small valves
Efficient Tool & Die Co.	Refueling-port housings
Elastic Stop Nut Corp.	Stop nuts
Electric Boat Div., General Dynamics Co.	Assisted in planning
Electric Steel Foundry Co.	Bodies for 18-in. stainless-steel valves, primary pump volute castings
Elliott Co.	Windings for main coolant pumps
Exide Industrial Electric Storage Battery Co.	Storage batteries
Electroweld Mfg. Co.	Handling equipment
Fairchild Camera & Instrument Corp.	Valve-position indicators, failed element detection and location system instrumentation
Fansteel Metallurgical	Special metals
Farris Engineering Corp.	Small valves
Ferrotherm Co.	Brazed water jackets
Firth Sterling, Inc.	Zircaloy tubing
Fischer and Porter Co.	Rotameters
Fisher Governor Co.	Small valves
Fisher Scientific	Scientific supplies
Flexitallic Gasket	Gaskets
Flexonics Corp.	Gaskets, special pipe
Fogleman Co.	Special fittings and valves
Follansbee Metals	Steel
Ford Instrument Co. Div., Sperry Rand Corp.	Instrumentation
D. D. Foster Co.	Liquid-level indicators
L. B. Foster Co.	Pipe, fittings
Foster-Wheeler Corp.	Steam generators, pressurizer
The Foxboro Co.	Flowmeters, recorders; D P cells, liquid-level transmitters
R. H. Freitag Manufacturing Co.	Large precision machining, final machining of bottom support plate
Frick & Lindsay Co.	Mill supplies
Fulton-Sylphon Div., Robertshaw-Fulton Controls Co.	Small valves
Garlock Packing Co.	Special packings and gaskets
General Electric Co.	Battery charger, single-phase underpower relays
General Ionics Corp.	Resins
Gibson Spring Co.	Supplied springs to valve suppliers
Goldsmith Bros. Smelting & Refining Co.	Precious metals
C. L. Gougler Machine Co.	Fabrication and final machining of bottom support plate adapters
Graybar Electric Co., Inc.	Electrical supplies
Grinnell Company, Inc.	Small valves, piping hangers
Griscom-Russell Co.	Heat exchangers, spray-water coolers
Hamill Manufacturing Co.	Small check valves, refueling-port plugs, penetration-housing seal-weld mockups, precision machinery
Hammond Iron Works	Machinery, storage tank
Hanover Tool Co.	Precision-machined parts
Harnischfeger	15-ton monorail hoists
Harris Pump & Supply Co.	Distributors for centrifugal and hydrostatic-test pumps
Hartford Electric Steel Casting Co.	Supplied large and small cast parts to valve suppliers
Hartford Steam Boiler Inspection & Insurance	Boiler-code inspection
Den Hartog	Consultant services
Harvey Aluminum Sales, Inc.	Special aluminum products
Haynes Stellite Co.	Raw materials, fabricated parts
Ralph A. Heller Co.	Special drills
Hermetic Seal Corp.	Seal for stop joints
Highway Products Co.	Ready-mixed concrete
Hills-McCanna Co.	Small valves
Hinkle Brothers, Inc.	Underwater-lighting assembly, mockup barrel and blanket disc assembly
Hoke, Inc.	Small valves
F. H. Hunter Co.	Port-selector shaft and hydraulic-inspection fixture
Industrial Instruments, Inc.	Conductivity cells and recorder
Industrial Products Co.	Connectors
Industrial Tectonics	Bearings
International Nickel Co.	Nickel, nickel alloys
Jerguson Gage & Valve Co.	Liquid-level indicators
Jerpbak Bayless Co.	Gages, tools, precision machinery
Jersey Chrome Plating Co.	Chrome-plated parts
Jessop Steel Co.	Stainless-steel bars and plates
Johns Manville Co.	Gaskets, packing
Johnson, E. A.	Cooling tower
Johnson Pump	Vertical turbine pumps
Johnson Service Co.	Automatic temperature-control system
Jordan Electronics Co.	Radiation survey meters
Joy Manufacturing Co.	Connectors
W. J. Keist & Son, Inc.	Air-conditioning equipment
Kelek Co.	Control board and miscellaneous equipment, waste disposal
Kett Corp.	Seal-weld cutting machines
Kewanee-Ross	Cooler
Kieley Mueller	Small valves
Koppers Co.	Exterior paint for reactor-plant container, chemicals, plastics

Suppliers to Shippingport (Cont.)

Supplier	Contribution to PWR
O. G. Kelly & Co.	Fabrications
M. W. Kellogg Co.	Heat exchanger
Keps Electric Co.	Electrical supplies
Kett Technical Center, Inc.	Closure seal-weld cutting machine
Kmet Tool & Manufacturing Co.	Small valves, precision machinery
Knapp Mills, Inc.	Lead bonding fabricator
Kollmorgam Optical Co.	Underwater optical equipment
B. M. Kramer Co.	Small valves, fittings, tools
L. E. Kraus Co.	Special drills
Kunkle Valve Co.	Small valves
Kutz Engineering & Construction Co.	Stands, racks
Kybernetes Corp.	Temperature monitor
Ladish Co.	Fittings
Lappe Supply Co.	Precision instruments
L & S Machine Company, Inc.	Precision machining; fabrications
Lawrence Pump Co.	Sump pumps
Lebanon Steel Foundry	Supplied large and small cast parts to valve suppliers
Leeds & Northrup Co.	Relay package for steam relief systems
Lehigh Engineering Associates	Drafting services
Leese & Orris	Tools
Kurt J. Lesker Co.	Conductivity cells and recorder
Frank Libuda, Inc.	Final machining of mechanism housings, instrument-port plug; precision machinery
Limbach Co.	Ventilating systems, brackets, fixtures, trellis terminal
Linde Air Products Co., Div. Union Carbide Corp.	Welding accessories
Linear, Inc.	O-rings
Litton Engineering Labs	Glass instruments
Lukens Steel Co.	Cladding materials for reactor vessel
Lunkenheimer	Small valves
Machine Shop Equipment Co.	Blanket-disassembly tool
Machine Tooling, Inc.	Blanket-disassembly tools
Magnaflux Corp.	Segment arms
Magnetrol, Inc.	Liquid-level switches
Manning, Maxwell & Moore, Inc.	Small valves, pressure gages, indicators, refueling crane
Marvel-Schebler Prod. Div., Borg-Warner Corp.	Control-rod drive mechanism
Mason-Neilan Regulator Co.	Small valves
Mason, Shaver & Rhoades	Shipping-container-plug tool, chill rings
Matheson Co., Inc.	Special gas, regulators
Magnetic Amplifiers, Inc.	Rod-limit magamps, rod-programming magamps
McDaniel Refractories Co.	Porcelain products
McJunkin Corp.	Piping
Mechanical Equipment Co.	Vapor compression-evaporation unit
Metals & Controls	Bi-metals and contacts
Micro-Metallic	Filters
Micro Switch Div., Minneapolis-Honeywell Regulator Co.	Special switches
Midvale Heppenstall	Stainless-steel and other alloy forgings
Ray Miller Co.	Pipe, fittings
Milwaukee Crane & Service Co.	125-ton crane
L. D. Mitchell's Plastic Studio	Plastic products
Moore Products	Ball-float operated level switches
A. B. Murray Co.	Stainless-steel pipe and tubing
Nash Engineering Co.	Spray recycle and stripper bottom pumps
National Annealing Box Co.	Fabrications
National Lead Co.	Lead bonding
National Tube	Water flasks, air bottles
National Valve & Mfg. Co.	Fabrications
New Departure Div., General Motors Corp.	Bearings
New England Power Service Co.	Assisted in planning
Newell & Sons	Screw machining
Newport News Shipbuilding & Drydock Co.	Assisted in planning
New York Lab Supply Co.	Laboratory supplies, chemicals
Norton Co.	Abrasives
Norwood Controls	Primary plant instrumentation, auxiliary instrument panel
NRD Instrument Co.	Hairpin loop monitor and probe, monitor lead shield, radiation detector
Nuclear Measurements Corp.	Crud probe, gross soluble-activity monitor, beta-gamma count-rate equipment
Ohio Injector Co.	Small valves
Ohio Steel Foundry	Castings for 18-in. valves
Wm. M. Orr	Aluminum, copper
Owens-Corning Fiberglass Corp.	Glass insulation
Pacific Valve Co.	Small valves
Panellit, Inc.	Auxiliary control board
Peerless Instrument Co.	Rod-position indicators, commutator inverters
Penn Electrical Co.	Rod-programming panel, relay test rack
Penn State Tool & Die Co.	Dust caps
Pennsylvania Alloy Machining Co.	Precision machining; head penetration housings, test plugs
Pennsylvania Industrial Supply	Copper, aluminum
Pfaudler Company	Vent condenser, palladium hydrogen-diffusion gage pre-heater, resin charging tanks
Philadelphia Pump Div., American Meter Co.	Hydrostatic-test pump
Pittsburgh Commercial Heat Treating	Heat-treated tubular housings
Pittsburgh-Des Moines Steel Co.	Vapor containers, refueling seals, core-cage barrel, mockup machinery, water-storage tank
Pittsburgh Gage & Supply Co.	Mill supplies
Pittsburgh Metal Fabricating Co.	Machining, pipe
Pittsburgh Piping & Equipment Co.	Fabricated main coolant piping, rough-machined and welded head-penetration housings; hydrazine; additional injection vessels
Pittsburgh Steel Corp.	Use of betatron facilities
Pittsburgh Testing Laboratory	Tested weldments
Potter Aeronautical Co.	Flow-measuring equipment
Powell Valve Co.	Small valves
Henry Pratt	48-in. butterfly valve
Precision Piston Rings, Inc.	Piston rings
Precision Shapes, Inc.	Machining
Pressure Products	Small valves, strainers
Process Engineering, Inc.	Palladium hydrogen-diffusion gage, hydraulic system for 48-in. butterfly valves, pilot ion exchanger
Protectoseal Co.	Safety equipment
Radform Tool Co.	Thermocouple lifting bail
Radiation Instrument Development Laboratory	Detector instrumentation
Radio Corporation of America	Boiler-water level gage, closed-circuit TV equipment, underwater television circuit
Radio Parts Co., Inc.	Electronic equipment
Ramsay Pump & Supply Co.	Small pumps
H. E. Ransford Co.	Instrumentation, electrical equipment
Reliance Electric & Engineering Co.	Pumps, electrical equipment
Republic Manufacturing Co.	Small valves
Reynolds Manufacturing Co.	Fabrications
Ritter Engineering Co.	Blanket-disassembly stand, hydraulic-cylinder assembly, water hydraulic-power unit
Rochester Manufacturing Co.	Thermometers
Ross Heat Exchangers	Heat exchangers
J. T. Ryerson & Son, Inc.	Mill supplies, steels, pipe
S. & Z. Tool & Die Co.	Water-jacket stampings

Suppliers to Shippingport (Cont.)

Supplier	Contribution to PWR
Sarco Co.	Float-traps
Saville & Co.	Special drills, taps, dies
Schutte & Koerting Co.	Small valves, strainers
Schwartz Boring Co.	Final machining of orifice housings
Schwartz Machine Co.	Final machining of head-closure housings
Scott Brown Corp.	Final machining of seed assembly
Shand & Jurs	Charging-water-tank-liquid-level control
Sheffield Corp.	Plug gages
Shields Rubber Co.	O-rings
SKF Industries	Bearings
S. Morgan Smith Co.	Final machining of core-cage and core-holddown barrels
South Hills Ornamental Iron Co.	Assembly stand
Southern Welding & Machine Co.	Test rig
Specialty Steel Products	Jig support, dismantling table
Spotweld Div., Otto Kongblow Mfg. Co.	Welding-mechanism components
Star Machine and Tool Co.	Machined parts
Stone & Webster Engineering Corp.	Engineering consulting service
Strohecker, Inc.	Fabrications
Superior Tube Co.	Special tubing
Superior Welding Co.	Incinerator and ash slurry tanks, separator drum, gas-decay drum
Supplies, Inc.	Mill supplies
Swartwout Co.	Instrument package for waste disposal system
Target Rock Corp.	Seal-weld cutting machine, core-hoisting equipment
Tark Lining Corp.	Trellis, access ladder assembly
Taylor Forge & Pipe Works	Fittings
Thermo Electric Co.	Thermocouples and wells
Thompson Products, Inc.	Mechanisms
Tigerman Engineering Co.	Annunciators
Tracerlab, Inc.	Mobile air-monitor units
Tri-State Machinery Co.	Machinery
Tube Turns Div., National Cylinder Gas Co.	Special tubing
United Shoe Machinery Corp.	Refueling and fuel-element extraction tools
U. S. Steel Corp.	Steel products
U. S. Tool & Die Company, Inc.	Precision machinery
Vapor Recovery Systems Co.	Small valves, tank-level gages
Vickers Electric Div., Vickers, Inc.	Nuclear-level magamps, pressurizer-heater controls
Victoreen Instrument Co.	Count-rate meters
Vitro Engineering Co. Div., Vitro Corporation of America	6-in. lattice test loop
Vulcan Machine Co.	Precision machinery; final machining of latch housings; inspection fixture, blanket-disassembly stand
Wall Colmonoy Corp.	Special brazing, rake assemblies, bottom bundle spacers
Walworth Co.	Small valves
Warren Corp.	Fuel-storage racks
Washington Tool & Machine Co.	Refueling-port seal-lip mock-up
Wedin Corp.	Machining, lead screws, spline shafts, latch rings, stub tubes
Westinghouse Electric Corp.	Primary 18-in. stop valves, main coolant pumps and volutes, small valves, multi-port sampling valve, blanket-water exit instrumentation, auxiliary seed instrumentation, a-c-d-c power-distributing panel, nuclear instrumentation, auxiliary rod-control panel, rod bottom magamp rack, 480-v substation, test fixtures, chill and grinding discs, tubes, refueling-crane controls, radiation-monitoring equipment
Whitney Tool & Die Co.	Instrument-well caps
E. L. Wiegand Co.	Replaceable pressurizer heaters, closure-stud heaters
Bud Wilco Co.	Final precision machining of instrument ports
Williams & Co., Inc.	Inconel, stainless steel, carbon, fittings
Worthington Corp.	Centrifugal pumps, effluent-transfer pumps, slurry pumps
Yarnall-Waring Co.	Strainers, drum-level indicator
Zallea Brothers	Bellows for reactor vessel filter
Zurn	Strainers

Load Cells

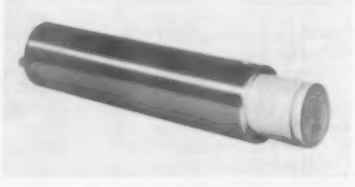
Series of precision strain-gage load cells (above) in hermetically sealed housings have capacities from 500 to 200,000 pounds. Rugged cell construction permits 225% overload without affecting calibration. Special cell cable has zero moisture absorption and stainless steel jacket.—Cox & Stevens Electronic Scales Div., Revere Corp. of America, Wallingford, Conn.

Columbium Melting Stock

Columbium metal melting stock of high purity is available in small cylindrical shapes that are easy to handle and weigh. These roundels, or shapes pressed from them, melt easily and cleanly. Extensive use as a base for a new series of high-temperature alloys is predicted for columbium metal because of its medium density and high strength at elevated temperatures.—Union Carbide International Co., 30 E. 42nd St., New York 17, N. Y.

Blind-Hole Inspector

Device for the inspection of holes to $\frac{1}{16}$ in. in diameter has a lens bulb, which shoots a concentrated beam of light into a hole too small for light probes, and a five-power telescope. The unit is powered by a transformer or battery unit that can be held in the inspector's hand.—Eder Instrument Co., 2293 N. Clybourn Ave., Chicago 14, Ill.



Probe Detector

Stainless-steel basic probe scintillation detector (above) is adaptable for use with many crystal and shield configurations. Crystals and shields are easily installed and removed from the probe by means of a threaded locking ring. Basic probe without crystal is available in three models: 11007 without preamplifier, 11008 with preamplifier and 11009 with cathode follower.—Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill.

Ultrasonic Cleaner

Ultrasonic cleaner (above) has a stainless-steel tank 9 × 14 × 13 in. deep that holds 5 gal. Water cooling of the nickel transducers allows the use of cleaning solutions up to 450° F.—Alcar Instruments, Inc., 17 Industrial Ave., Little Ferry, N. J.

125-Mc Delay Line

Model V-215 (above) is a 125-Mc delay line that has a total delay of 50 μsec and an impedance of 50 ohms. Designed for a continuous motor-driven application, it is constructed with a rugged printed-circuit commutator-type switch having rhodium plated segments and a silver alloy wiper arm. Resolution is one part in 120.—Control Electronics Co., Inc., 1925 New York Ave., Huntington Station, N. Y.

Heat-Exchanger Coils

Coils for various heat-exchange duties in process industries, including Al, Cu, and stainless as well as carbon, alloy and hot-dipped galvanized steel are fabricated in both prime- surface and extended-surface types. Coil types include series flow, serpentine and

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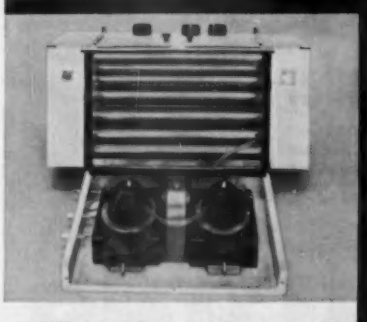

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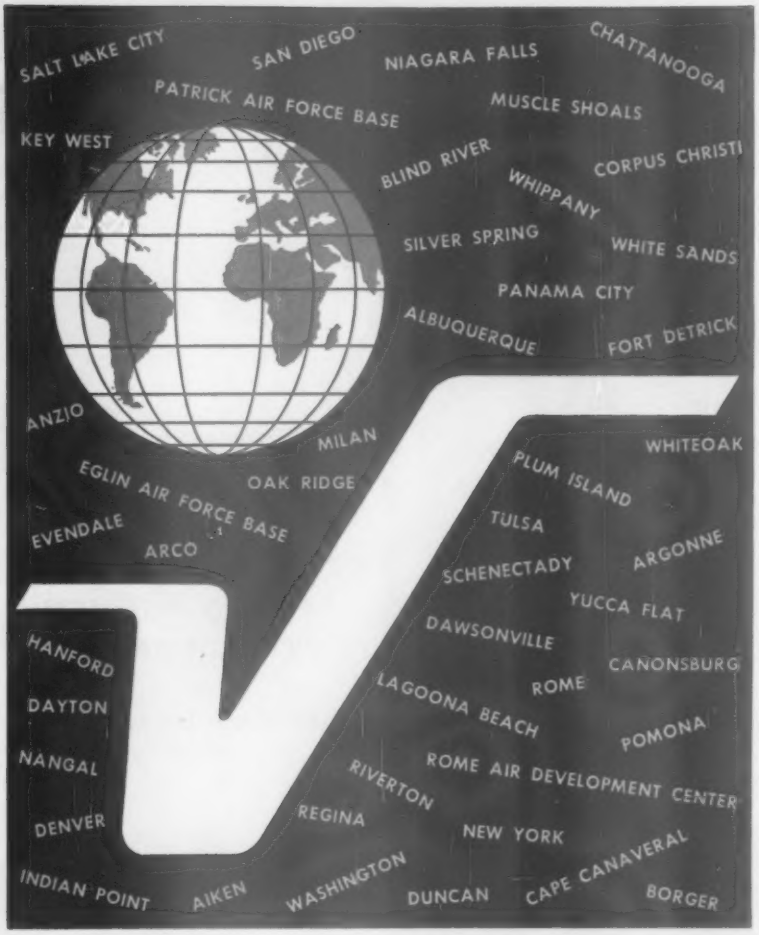

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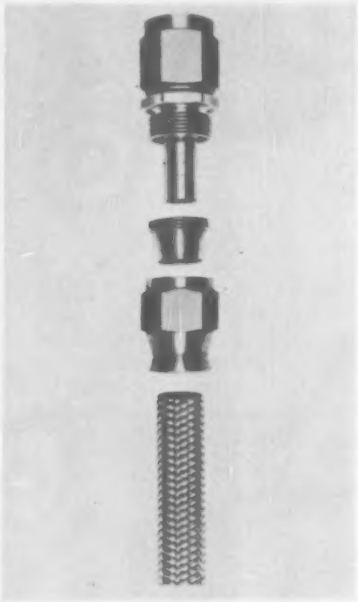
parallel flow with special headers. They are fully cleanable, variously partitioned and with bends to various radii for pressures up to 3,000 psi.—Niagara Blower Co., 405 Lexington Ave., New York 17, N. Y.



Reusable Fitting

Seal-Lock (above) is a reusable fitting for use with high-temperature Teflon hose. By means of a triple locking feature, they are locked to the hose and the components are locked to each other.—Resistoflex Corp., Roseland, N. J.

Fluorometer

New model of the noted Galvanek-Morrison Fluorometer (above), de-

veloped originally for AEC by the American Cyanamid Co., now incorporates provision for the analysis of liquid samples for trace quantities of both Be and U.—Jarrell-Ash Co., 26 Farwall St., Newtonville 60, Mass.

Beta Gages

Two beta-ray thickness gages are available; the twin-channel Model N562 is ideal for high-speed production line use where highest long-term stability with minimum surveillance is of prime importance; the single-channel model N565 is most suitable for laboratory and short-run production applications where sheeting or coating densities change with each job order. Both models use a vibrating reed electrometer in the electronic circuit instead of the conventional d-c amplifier. Standard source detector frames are available up to 5 ft long with other sizes to special order.—American Tradair Corp., 34-01 30th St., Long Island City 6, N. Y. (Distributors for EKCO Electronics, Ltd., Essex England.)

Spectrum Recorder

Model 701 (above) is an instrument employing a strip chart recorder for automatic plotting of pulse height spectra in conjunction with scintillation counting equipment incorporating a single-channel pulse-height analyzer and ratemeter. The chart recorder drum is directly coupled to a 355-deg potentiometer. This varies the discriminating voltage of the pulse analyzer while the pen movement (controlled by the ratemeter) follows the corresponding pulse rate. The scanning time can be switched to 10 min or 1 hr, and the chart length per scan is 6 in. Each 6-in. record represents a scan over either the complete voltage range or the upper half of the voltage range, as selected by a two-position switch.—Isotope Developments Ltd., Beenham Grange, Aldermaston Wharf, Berkshire, England.

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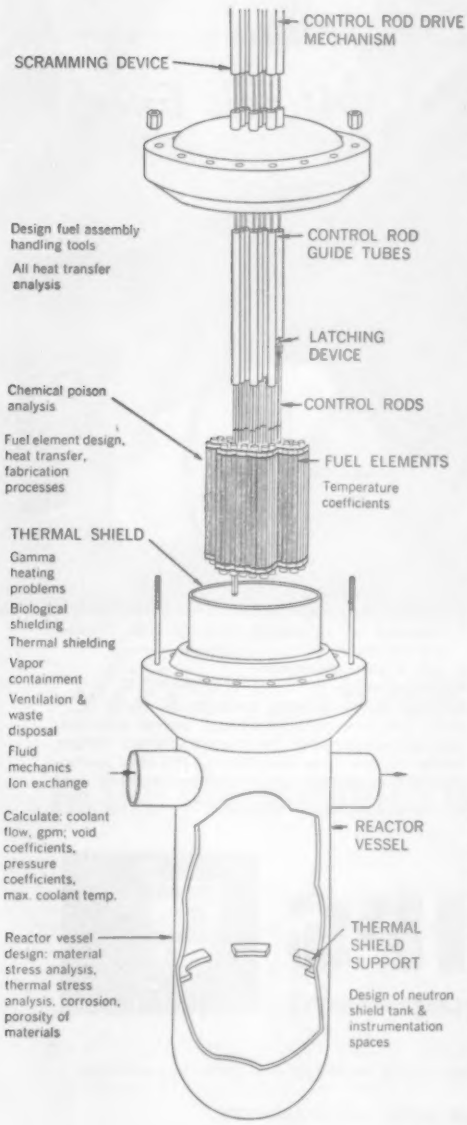
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Department starts on page 118

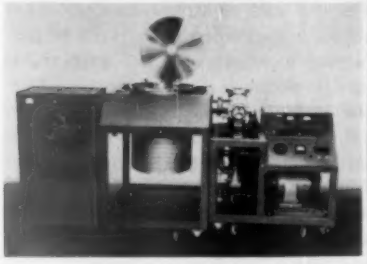
Electric Counter

Model 5-YE (above) is a high-speed electric counter (register) that counts up to 1,500 cpm. Counters are offered in four models: panel mounting or base mounting and electric reset or push-button reset. Large ($\frac{3}{16}$-in. high) white figures on a black background are set high in the window for maximum visibility.—Durant Mfg. Co., 1999 N. Buffum St., Milwaukee 1, Wis.

Mobile Weld Analyzer

To meet government requirements for recording instrumentation of stored-resistance welding machines, a weld analyzer recorder (above) has been developed that simultaneously depicts and records current and force applied to electrodes. The instrument will reliably record strains as low as 10 μin./in. and currents as low as 1 ma. Weighing 100 lb and standing only 31 in. high, it contains a direct-writing two-channel recorder driven by a con-

denser-coupled amplifier and a universal-carrier amplifier—Edin Co., 207 Main St., Worcester 8, Mass.



Laboratory Vacuum Furnace

Model F-15 (above) is a laboratory vacuum furnace built on the modular principle for maximum adaptability. The complete furnace assembly is capable of all the following vacuum or inert-gas operations: melting, casting, annealing, alloying, sintering, heat treating and crystal growing. In addition, the furnace can be quickly converted to a high-vacuum evaporator by attaching a special base plate assembly and an 18 × 30-in. bell jar to the pumping unit. Capable of temperatures in excess of 2,000° C and a crucible capacity of 5 lb. of steel (or equivalent in other metals), the F-15 can reach a pressure of 1×10^{-4} mm Hg in 20 min and an ultimate pressure of 1×10^{-5} mm Hg.—Kinney Mfg. Div., The New York Air Brake Co., 3529 Washington St., Boston 30, Mass.

LITERATURE AVAILABLE

Transitorized equipment is covered in 10-p. catalog.—Electronic Research Associates, Inc., 67 Factory Pl., Cedar Grove, N. J.

Accelerometers are covered in 4-p. Bulletin 410.—Donner Scientific Co., Concord, Calif.

Level measurement and control systems (capacitance type) are described in 16-p. booklet.—Robertshaw-Fulton Controls Co., 2920 N. 4th St., Philadelphia 33, Pa.

Government specifications for adhesives and sealing compounds; paints, enamels, varnishes and coating materials; cleaning compounds, solvents and miscellanea are listed according to number in 11-p. catalog.—Dept N437, Magic Chemical Co., 121 Crescent St., Brockton 2, Mass.

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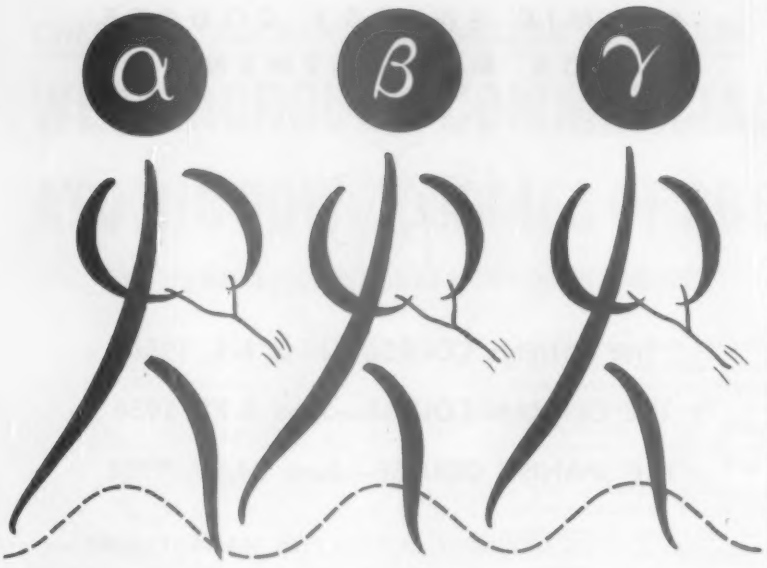

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NUCLEAR CAMPUS

• **The University of Michigan** is stepping up its support of research on peaceful uses of atomic energy. The school has awarded new grants to ten faculty members and has authorized its Development Council, on behalf of the Memorial Phoenix Research Project, to raise $2-million for a five-year nuclear research program beginning July 1, 1959. The Council has authority to accept donations up to that amount for undesignated research use, but may also accept funds beyond the goal, subject to use as designated by the donor.

• **The Oak Ridge Institute of Nuclear Studies** has sent two of its special training staff, Lawrence K. Akers and H. K. Ezell, Jr., to Beirut, Lebanon, to aid in the presentation of a four-week course in radioisotope technique. Sponsored by the International Cooperation Administration, the course is being conducted at the University of Beirut. It is similar to a course conducted regularly at ORINS, with more emphasis on medical applications.

• **The American Society for Engineering Education** has appealed for expanded national support for fundamental research. Representing most U. S. engineering colleges, ASEE said "another $10-million could be accommodated immediately" to supplement an estimated $100-million already being spent on college campuses. The group recommended a five-point program to James R. Killian, Jr., presidential adviser on science and technology: **1.** increase federal basic research contracts with universities; **2.** encourage graduate participation; **3.** compensate the universities for indirect, as well as direct costs; **4.** support construction of new or enlarged facilities for fundamental engineering; and **5.** provide long-term research contracts.

Courses

Lowell Technological Institute will inaugurate a **nuclear engineering curriculum** this fall for education of both engineers and chemists. The program's eventual objective is the training of nuclear scientists on the graduate level, engineers on the undergraduate level and technicians on the associate-degree level. The following have agreed to serve on a nuclear engineering advisory committee: Bruce H. Billings,

Baird-Atomic; Roger J. Coe, Yankee Atomic Electric; Clark D. Goodman, AEC reactor development division; Thomas H. Johnson, Raytheon; Albert R. Kaufmann, Nuclear Metals; and Marvin G. Schorr, Technical Operations, Inc.

The third annual summer program in **nuclear energy for industry** will be held at the Berkeley campus of the University of California in June, July and August. It includes a nine-week technical course in engineering, a week-long course for management on industrial applications, and field trips in the Bay area. Tuition is $800 for the technical course, $150 for businessmen.

A voluntary, noncredit course on **scientific Russian** has had an unprecedented response at Argonne National Laboratory. Morton Hamermesh, associate director of ANL's physics division and the course instructor, has had an enrollment of 120 for this year's class, "far greater" than attendance at two previous courses.

City College of New York has introduced a **graduate program in nuclear engineering** this term through its School of Technology. The school is offering production of reactor materials and reactor engineering in this spring term, to be followed by laboratories on nuclear engineering and nuclear science for engineering, and a class on reactor construction materials. Program supervisor is Morris Kolodney, coordinator of nucleonics at CCNY.

A home-study course in nuclear engineering will be offered this fall by CREI Atomics, Inc., a new subsidiary of Capitol Radio Engineering Institute, Washington, D. C. CREI Atomics' educational director is Charles De Vore, former assistant technical information officer at the Naval Research Laboratory.

Queen Mary College, University of London, has scheduled its first **post-graduate course in nuclear engineering**—three terms beginning in October. Chief object is to give theoretical and experimental grounding in the basic concepts and measurements of nuclear particles and radiations, relating this knowledge to reactor design. The program calls for lengthy experiments with a sub-critical assembly and research reactor. Contact Registrar, Mile End Road, London, E. 1.

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NEWSMAKERS

L. William Kates has been elevated to director of engineering by Sylvania-Corning Nuclear Corp. The firm maintains its headquarters at Bayside, L. I., with production facilities in Hicksville, L. I. Kates has been, since 1947, successively engineer and section head of Sylvania Electric's metallurgical lab, engineering manager of Sylvania's atomic energy div., and manager of Sylvania's commercial development div.

Kates

AEC has appointed **Robert B. McCalley, Jr.**, reactor containment engineer in the reactor development division. He will follow the structural research work on reactor containment being sponsored by AEC. McCalley joined AEC from Knolls Atomic Power Laboratory, where he worked on stress and vibration analysis for reactor components.

Jan H. A. Rydberg has taken a one-year leave of absence as chief of nuclear chemistry at Sweden's Research Institute of National Defense to join the chemistry staff of Argonne National Laboratory. He plans to extend his work in the chemistry of the actinides, concentrating on neptunium and berkelium.

William J. Grady, Burns & Roe project manager for the Shippingport reactor, has won promotion to manager of construction for Burns & Roe, engineers and builders of the 60 Mw(e) plant. Grady has returned to the firm's headquarters in New York City after some three years on the Shippingport project. The station was completed last fall and went critical Dec. 2.

Grady

AEC has firmed up its top-level legal staff, bringing in **Loren K. Olson**, a Washington, D. C., attorney as its general counsel and naming **Edward Diamond** associate general counsel. Diamond has been acting general counsel since June, 1957, when William

Mitchell resigned. Olson is a graduate of Wisconsin U. Law School (1940) and has held legal posts with the Wisconsin Industrial Commission, the National Labor Relations Board and the Navy Dept. He was a partner in the Washington firm of Shook and Olson.

H. A. C. McKay has been appointed director of the Baghdad Pact Nuclear Training Center. A group leader in the chemistry division, U. K. Atomic Energy Authority, McKay will take his new post in July, succeeding W. J. Whitehouse.

The International Atomic Energy Agency has added two directors: to head the legal division, **Joseph Esser,** a member of the West German Atomic Energy Commission and legal adviser to the Ministry for Atomic Matters; and heading the financial division, **Badr el-Din Hamdi,** deputy director general of the Egyptian Finance Ministry. They join eleven other division directors named earlier (NU, March '58, 26).

H. D. Vollmer, Jr., has been picked to head the new Atomic and Marine Div. of Bailey Meter Co. The Cleveland firm manufactures industrial instruments and automatic controls for power and process industries.

Ralph G. Bates, development engineer, has been promoted to general sales manager, Kaiser Engineers. He will direct sales activities in the nuclear, petroleum, thermal power and minerals industries and for government projects.

Allis-Chalmers has added an assistant engineer in reactor dynamics to its nuclear power division—**David H. Crimmins, Jr.,** a Detroit U. graduate.

Physicist **Charles M. Eisenhauer** has joined the staff of the atomic and radiation division at the National Bureau of Standards. He is coordinating theoretical and experimental research on protection afforded by homes and structures against nuclear radiation.

Wayne P. Brobeck, staff associate with American Research and Development Corp., has won promotion as vice president of its affiliate, Ionics, Inc. Before joining the parent firm, Brobeck spent 10 years as production expert for the Joint Congressional Committee on Atomic Energy. He will handle government contracts and nuclear activities for Ionics.

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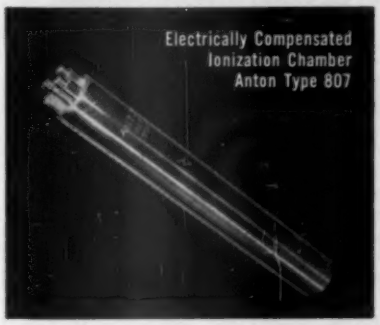

- Rugged, unitized electrode structure enables the chamber to operate in any position, withstand shock and vibration conditions present during propulsion reactor operation.
- All-ceramic insulation to permit high temperature operation impossible to achieve with conventional plastic insulators.
- Magnesium-Aluminum alloy electrodes contained in an all-welded aluminum envelope.
- Electrically compensated...guard ring design.
- Flake-proof B^{10} coated electrodes.
- Longer life and greater electrical stability assured by advanced mechanical design that permits evacuation and processing at high temperatures.

Operational Data

1. Operating thermal neutron flux range: 2.5×10^2 to 2.5×10^{10} neutrons/cm²/sec.
2. Thermal neutron sensitivity: 4×10^{-14} amps/unit neutron flux
3. Gamma sensitivity: 3×10^{-11} amps/R/hour
4. HN connectors in circular array for easy connection to commercially available HN type cable fittings. Mate with Amphenol 82-38 (MIL-UG 59 A/U or equal)
5. Overall dimensions: 3-1/8 ± 1/16" dia. x 23-3/4 ± 1/4" long
6. Sensitive length: 14-1/16" approximate

A wide range of improved neutron proportional counters is available with a variety of all-welded cathode materials (stainless steel, aluminum). In addition to standard catalog items, sizes can be supplied ranging from ¼" dia. x 1" long to 2" dia. x 30" long. Minimum wall thickness for Al is 0.010"; stainless steel minimum is 0.002". Connectors can be supplied per your specification.

High temperature operation of Anton neutron detectors is made possible by the use of thermally matched seal components . . . high temperature ceramic insulators . . . unique processing and seasoning . . . restriction to high temperature organic moderators where needed.

Multi-element, high sensitivity counters encased in super Dylan moderators can be supplied from production to provide thermal and intermediate neutron sensitivity up to 45 counts/neutron/cm².

Fills and pressures are available up to 2 atmospheres. A closely supervised gas purification system allows versatile application of spectroscopically pure normal (18% B^{10}), depleted (10% B^{10}) or enriched (96% B^{10}) Boron Trifluoride fills. Special zone temperature controlled muffle furnaces provide the most uniform method of Boron coating available to date.

Uniform, stable characteristics are assured from tube to tube. High temperature, high vacuum outgassing techniques are used for all components. The metal to ceramic seals are permanently fused and the exhaust tip is concealed. All parts are processed by patented methods to make them extremely resistant to the corrosive effects of BF_3. The insulators are precision molded, mechanically rugged and chemically inert.

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NUCLEAR CALENDAR

April 19–25—Thirteenth National Industrial Health Conference, Atlantic City. Emphasis on hazards introduced by changing technology, including radiation. Contact Mrs. Tula S. Brocard, Rm. 2029, Temporary R, 300 Independence Ave., S. W., Washington 25, D. C.

April 20–23—Canadian–U. S. chemical engineering conference, American Institute of Chemical Engineers and Chemical Institute of Canada, Montreal. Contact H. R. L. Streight, DuPont Co. of Canada, PO Box 660, Montreal, Quebec, Canada.

April 25—Evening panel discussion on "The True Economics of Nuclear Power," sponsored by Northeastern New York Section, American Nuclear Society, Schenectady (*GE Research Laboratory Auditorium*). Panelists will be Karl Cohen, GE Atomic Power Equipment Dept.; L. G. Cook, GE Research Laboratory; and Donald H. Stewart, AEC. Contact D. W. Lillie, GE Research Laboratory.

April 27–May 1—Annual spring meeting, Electrochemical Society, New York (*Statler*). Symposium on "The Preparation, Evaluation and Uses of High-Purity Metals." Contact M. A. Steinberg, Horizons, Inc., 2906 East 79th St., Cleveland 4, Ohio.

May 1–4—Italian Society of Radiology and Nuclear Medicine, 20th Congress, Cagliari, Italy. Contact Society, Via Comelico 2, Milan.

May 2—Fifth Annual Conference for Engineers and Architects, sponsored by Ohio State University's College of Engineering, Columbus, Ohio. Session on nuclear engineering, including power reactor trends, nuclear fuel processing, waste disposal, metallurgy and cost of nuclear fuel, and nondestructive testing of nuclear components. Contact Ohio State Univ. Bureau of Public Relations, Columbus.

May 6–8—Annual meeting of American Public Power Assn., New Orleans (*Roosevelt*). Afternoon session May 8 on nuclear power. Contact Alex Radin, Suite 210, 1025 Connecticut Ave., Washington, D. C.

May 24–31—International Water Supply Assn., 4th Congress, Brussels. Lecture on atomic energy and its relation to water supply. Contact L. Millis, International Water Supply Assn., 10 Square Ambiorix, Brussels 4.

May 27–29—Third annual reactive metals conference, American Institute of Mining, Metallurgical and Petroleum Engineers, Buffalo (*Statler*). Contact S. F. Urban, National Lead Co., Buffalo, N.Y.

June 2–5—American Nuclear Society

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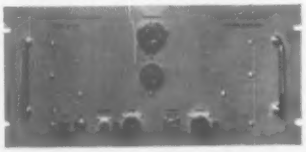

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annual meeting, Los Angeles (*Statler*). Contact W. R. Hainsworth, Fluor Corp., Los Angeles.

June 2–6—Symposium on the Peaceful Uses of Atomic Energy in Australia, Sydney. Exhibition and five-section conference—materials, power engineering, power auxiliaries (fuel cycles, chemical processing, economics), basic sciences (nuclear and thermonuclear), and associated techniques (radioisotopes, handling instrumentation, health, education, training). Contact Symposium General Secretary, AAEC Research Establishment, Sutherland, New South Wales, Australia.

June 2–7—International Conference on Solid State Physics in Electronics and Telecommunications, Brussels. Scheduled in conjunction with Brussels Fair. Papers on radiation-sensitive materials, phosphors, electroluminescent materials, infrared detectors, image amplifiers, light amplifiers, etc. Contact General Secretary, Société Belge de Physique, Loverval, Belgium.

June 9–11—Annual meeting of Health Physics Society (*University of California, Berkeley*). Contact Elda E. Anderson, Oak Ridge National Laboratory, Tenn.

June 19–21—5th annual meeting, Society of Nuclear Medicine, Los Angeles. Seminar on teaching problems in use of radioactive isotopes features program which includes 30 scientific papers and four training courses. Contact G. C. Kyker, ORINS Medical Div., Box 117, Oak Ridge, Tenn.

June 23–27—1958 Gordon Research Conference on Nuclear Chemistry, Meriden, N. H. (*Kimball Union Academy*). Talks on nuclear spectroscopy, photonuclear reactions, heavy ion reactions, hot atom chemistry, chemical techniques. Contact W. George Parks, U. of Rhode Island, Kingston.

June 30–July 5—2nd Conference on High Energy Nuclear Physics, European Council for Nuclear Research, Geneva. 8th in series of annual conferences hitherto held in Rochester, N. Y. Contact CERN, Geneva 23, Switzerland.

July 7–12—International Congress on Nuclear Physics, Paris, sponsored by the International Union of Physics and the United Nations Economic and Social Council. Contact F. Netter, Institut du Radium, 11, rue Pierre Curie, Paris 5.

Sept. 1–13—Second International Conference on Peaceful Uses of Atomic Energy, Geneva, sponsored by United Nations. For preliminary program, see NU, Aug. '57, 23. As in 1955, there will also be both government-sponsored and industrial exhibits. Contact Sigvard Eklund, United Nations, N. Y.

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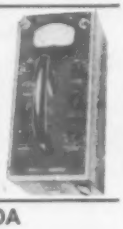

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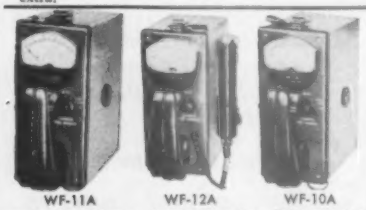

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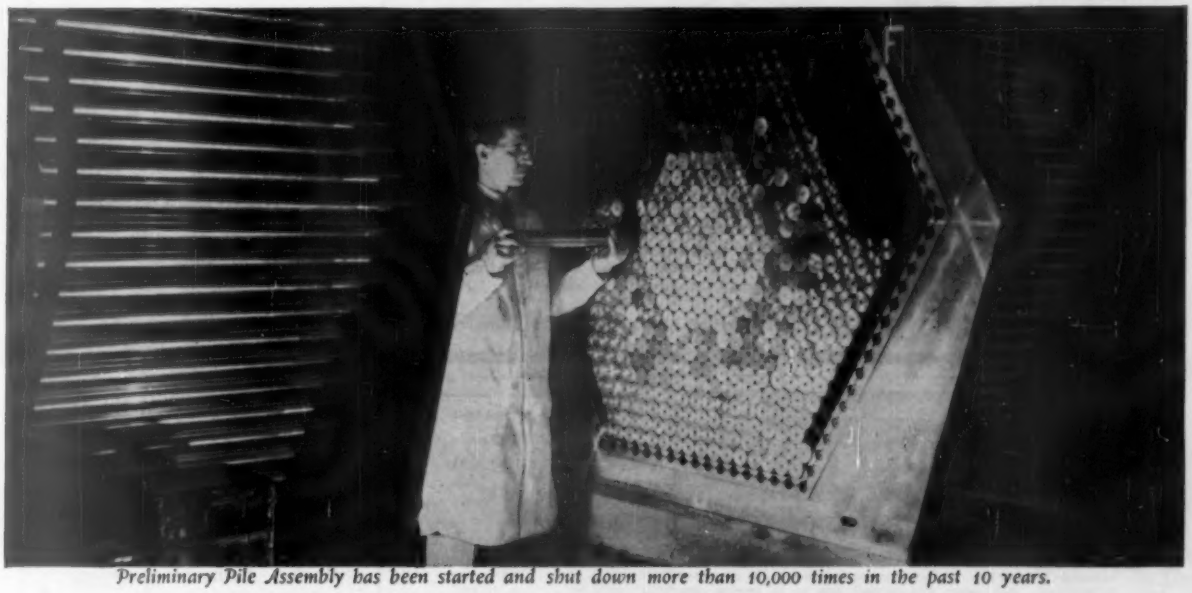

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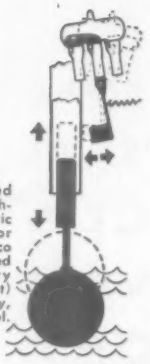

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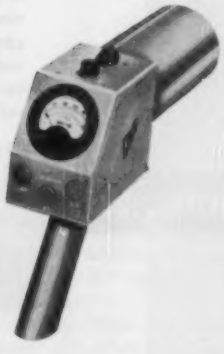

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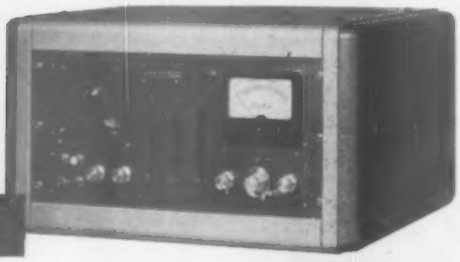

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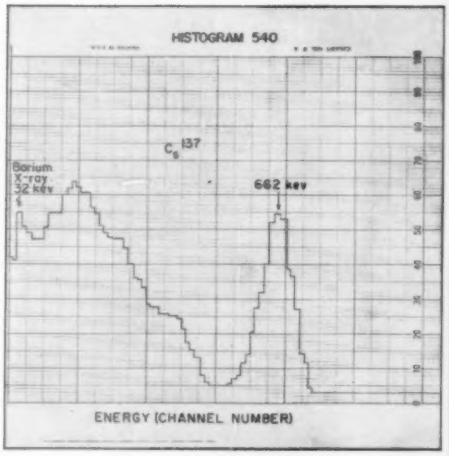

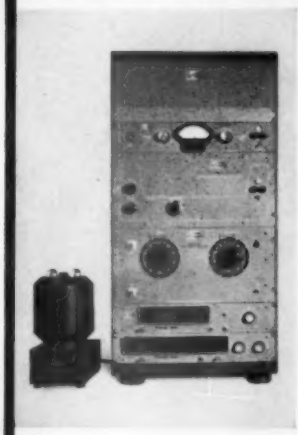

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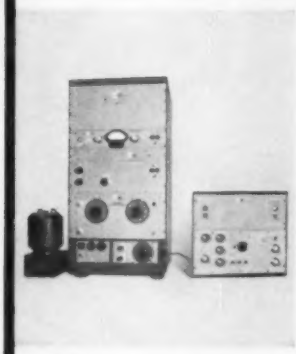

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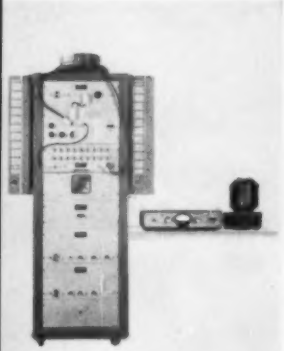

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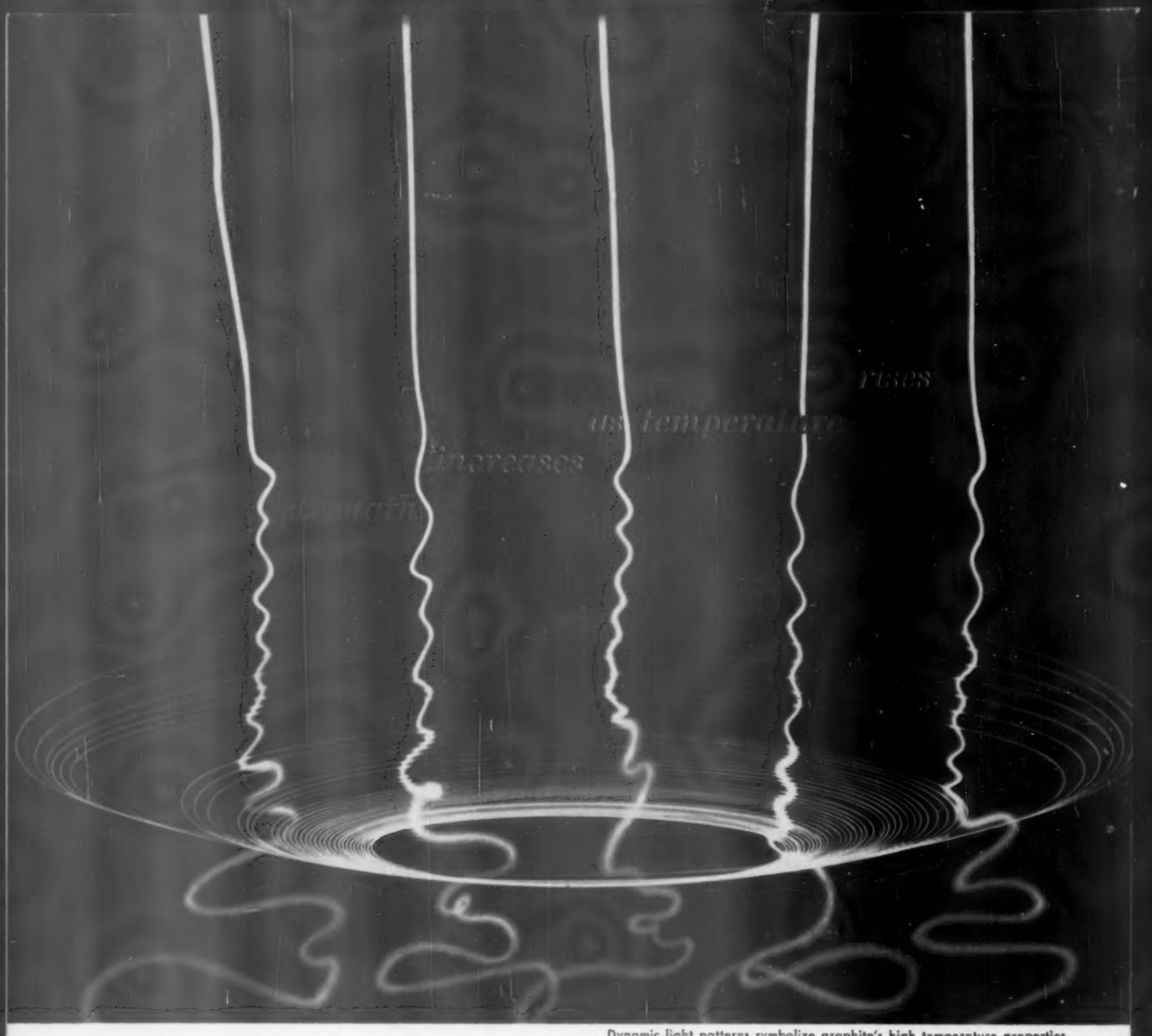

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